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ELEMENTS

OF

CHEMICAL AND PHYSICAL

GEOLOGY.

BY

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TABLE OF CONTENTS.

CHAPTER XLIV.

CHEMICAL REACTIONS RELATING TO THE ALTERATION AND PRODUCTION OF MINERALS.

PAGE
Reduction of peroxide of iron by organic substance 1
Reduction of persilicate of iron by organic substance 3
Blue clay of the silurian rocks in Russia 4
Influence of the presence of organic substance on the metamorphism of rocks 5
Production of green earth 5
Displacement of carbonic acid from water 5
Decomposition of bicarbonate of lime by atmospheric air 6
Carbonate of lime in mineral water 8
Conditions of the deposition of carbonate of lime and other calcareous salts 12
Production of limestone 13
Decomposition of bicarbonate of iron by atmospheric air 13
Production of ferruginous deposits 14
Decomposition of silicate of soda by carbonate of lime 14

CHAPTER XLV.

GENERAL REMARKS ON ROCKS.

Uncertainty as to which rocks are the oldest 16
Connection between the character and origin of rocks 17
Classification of rocks 17

CHAPTER XLVI.

SEDIMENTARY ROCKS.

Occurrence and production of sedimentary rocks 18
Slaty cleavage and stratification 19
Delta formations 20
Sedimentary deposits from suspended substance of rivers 22
Influence of the tides on deposition of suspended substance 22
Amount of suspended substance in rivers 23
Amount of lime supplied to the sea by river-water 24
Difference in the deposition of suspended and dissolved substance 24

PAGE
Alteration of fossil remains in rocks 25
Succession of strata in different geological series 26
Changes in the fall of rivers 26
Influence of lakes on the course of rivers 27
Formation of valleys and rivers 28
Retrogression of waterfalls 28
Deepening of valleys and alteration of watercourses 29
Transport and deposition of detritus by rivers 30
Effects of deposition by rivers 31
Probable former course of the Rhine 32
Changes in the beds of rivers 33
Production of limestone strata 34
Influence of organic life on the deposition of carbonate of lime 35
Limestone not a mechanical deposit 36
Source of the carbonate of lime in primitive limestone 36
Probable increase in the amount of carbonate of lime in river-water at the present time 37
Alteration of sedimentary strata 38
Composition of the deposits under Amsterdam 39

CHAPTER XLVII.

CRYSTALLINE ROCKS.

Classification of crystalline rocks according to structural and chemical characters 42
Occurrence and production of crystalline rocks 43
Evidence that crystalline rocks are not of igneous origin 43
Rudberg's experiments on solidification of melted masses 43
Sequence in the production of minerals constituting rocks, inconsistent with their crystallization from melted masses 44
Instances of the relation of minerals in crystalline rocks 45
Columnar structure of granite 46
Fournet's hypotheses of superfusion 47
Daubree's theory of the production of granite 48
Character of the granite that would result from the reaction of chloride of silicium vapour with bases 49
Quartz crystals in trachytic lava 50
Crystallization of minerals in lava 51
Thin veins of granite traversing hornstone, etc. 52
Clay-slate not always crystalline where in contact with granite 52
Composition and characters of trachyte-porphyry lava, as compared with those of granite 53
Influence of chemical alteration on the fusibility of rocks 54
Geognostic relations of crystalline and other rocks 54
Phenomena of elevation in the Fassathal 54
v. Buch's hypothesis of elevation by erupted masses 55
Assumed origin of granitic veins 55
Dislocation and fracture of sedimentary rocks in contact with crystalline and trapp rocks 55

PAGE
Phenomena of volcanic elevation on the left bank of the Rhine 56
Characters of the clay-slate adjoining the trachytic cones on the right bank of the Rhine 56
Origin of hydrated minerals in rocks 57
Alteration of rocks in the wet way, a constant process 57
Iron pyrites in crystalline rocks 58
Action of heat on iron pyrites 58
Production of sulphide of iron in crystalline rocks 58
Decomposition of crystalline rocks 59
Peroxidation of protosilicates of iron in rocks 60
Action of glacier-water on Alpine rocks 61
Influence of the presence of organic substance on water 62
Action of water on rocks at great depths 63
Products of the decomposition of crystalline rocks 63
Origin of clay 64

CHAPTER XLVIII.

METAMORPHIC ROCKS.

Classification of metamorphic rocks 65
Indications of the metamorphism of rocks 65
Frequent occurrence of metamorphic rocks 66
Reduction of persilicates of iron 67
Probable origin of clay-slate 67
Crystalline rocks presenting stratification 68
Phenomena presented by sedimentary rocks in contact with igneous rocks 68
Action of heat on quartz pebbles 69
Influence of heat on lias-slate, etc. 70
Difference between the effects of heat on rocks, and the characters of metamorphic rocks 71
Action of water-vapour on sedimentary rocks 71
Phenomena presented by rocks adjoining suffioni, etc. 72
Characters of masses constituting dykes 73
Saalbands in basaltic dykes 73
Characters of clay-slate in contact with basalt 74
Origin of the carbonate of lime and iron ochre, near the line of contact 74
Probable obliteration of the effects of heat by the action of water 75
Characters of brown coal measures traversed by basaltic dykes 76
Opposite effects ascribed to the action of heat 77
Bleaching of red sandstone in contact with basalt 78
Columnar structure of rocks in contact with basalt 79
Unaltered rocks in contact with melaphyr dykes 80
Silicification and induration of rocks 81
Characters of granite imbedded in basalt 81
Red colour of shale in contact with greenstone, etc. 82
Conversion of trachytic conglomerate into pitchstone 83
Rocks in contact with porphyry, syenite, and granite, rarely present indications of alteration 83

PAGE
True nature of the alteration of rocks at the line of contact 84
Unaltered sedimentary strata between metamorphic and crystalline rocks 85
Local alteration of rocks 86
Differences in the alteration of rocks when exposed to the atmosphere and when protected from it 86
Metamorphic processes progressive 87
Action of caustic and carbonated alkalies upon rocks 87
Extraction of constituents from rocks 89
Influence of carbonate of lime and silica in the alteration of rocks 91
Crystalline rocks do not present the same characters as when originally produced 91
Partial obliteration of structure in the metamorphism of sedimentary rocks 92

CHAPTER XLIX.

SANDSTONE.

Occurrence and composition of sandstone 93
Quartz in sandstone 94
Cementing material of sandstone 95
Analyses of sandstone 96
Removal of cementing material of sandstone 98
Analyses of quader sandstone 99
Kaolin in sandstone 100
Analyses of green sand, etc. 101
Amounts of carbonate of lime in sandstone 102
Cementing material of planer sandstone 103
Sandstones of Moravia 104
Tertiary sandstone 105
Cementing material of sandstone at Fontainbleau 106
Origin of the cementing material of sandstone 107
Production of sandstone 108
Organisms in mud and sand from the bottom of the ocean 109
Separation of silica from sea-water 110
Alteration of sandstone 111
Siliceous concretions in clay 112
Origin of mica in sandstone 113
Felspar crystals in sandstone 114
Decomposition of sandstone 115
Analyses of decomposed sandstone 116

CHAPTER L.

SEDIMENTARY LIMESTONE.

Occurrence and production of sedimentary limestone 116
Deposition of carbonate of lime 117
Calcareous deposits in rivers, etc. 118

CHAPTER LIII.

DOLOMITE.

PAGE

Geognostic characters of dolomite 155

Difference of texture between dolomite and granular limestone 156

Fissured condition of dolomite 157

Hypotheses of the production of dolomite 158

Action of magnesian salts on carbonate of lime 159

Dolomite not produced by volcanic heat 160

Deposition of carbonate of magnesia with carbonate of lime 161

Quartz associated with bitter-spar 162

Silicates in dolomite and limestone 163

Pseudomorphous steatite after bitter-spar, etc. 163

Conversion of dolomite into steatite 164

Pseudomorphous bitter-spar after calc-spar 165

Conversion of limestone into dolomite 166

Action of water on a mixture of carbonates of lime and magnesia 167

Deposition of carbonates of lime and magnesia from water 168

Composition of acid carbonates 170

Solution of carbonate of lime from rocks 172

Carbonates in water 173

Pseudomorphs after calc-spar 174

Conversion of calc-spar into bitter-spar 175

Carbonate of iron in sedimentary deposits 176

Mixed mechanical and chemical deposits 176

Carbonate of magnesia in deposits from water 177

Carbonate of magnesia in sea-water 178

Analyses of limestone imbedded in basalt 179

Conversion of limestone into dolomite 180

Carbonate of magnesia in marly strata 181

Origin of magnesian masses in limestone strata 182

Analyses of shelly limestone and dolomite 183

Association of limestone and dolomite 184

Characters of the dolomite in the Lahn district 185

Manganese ores in dolomite 186

Assumed production of dolomite by magnesian vapour 187

Production of dolomite by the action of water 188

Alteration of limestone 189

Formation of caves in limestone 190

Denudation of limestone by water 191

Alternate solution and deposition of carbonate of lime 192

Fissured condition of dolomite, caused by the action of water 193

Association of clay with dolomite 194

Action of carbonated water on magnesian limestone 195

Calc-spar in cavities of dolomite 196

Origin of manganese ores associated with dolomite 197

Conversion of transition limestone into dolomite, etc. 198

Rocks associated with dolomite 199

PAGE
Removal of carbonate of lime by water 200
Dolomite of the Tyrol 201
Carbonate of magnesia in the limestone of the Tyrol 201
Dolomite not produced by deposition 202
Magnesian deposits in rivers 202

CHAPTER LIV.

AUGITIC ROCKS.

Varieties of augitic rocks 203
Characters of augitic porphyry 204
Melaphyr in Rhenish Bavaria 204
Carbonate of lime in melaphyr 205
Decomposition of melaphyr 206
Action of water on melaphyr 207
Jasper in augitic porphyry 208
Association of greenstone and augitic porphyry 209
Diverse products of the decomposition of melaphyr 210
Analyses of augitic rocks 211
Determination of the constituents of augitic labradorite rocks 215
Oligoclase in augitic rocks 215
Nephelin and olivine in augitic rocks 216
Magnetic oxide of iron in augitic rocks 217
Defects of the separate analysis of the soluble and insoluble portions of augitic rocks 218
Analyses of melaphyr 220
Constituents of the matrix of melaphyr 222
Hornblende in melaphyr 223
Diminution of the amount of lime in melaphyr 224
Water in labradorite 225
Bases removed in greater amount than silica, in the decomposition of melaphyr 226
Difference in the alteration of amorphous and crystalline portions of melaphyr 226
Quartz in melaphyr 227
Ferruginous chlorite in melaphyr 228
Quartz and epidote in amygdaloid rocks 229
Iron pyrites in melaphyr 230
Analyses of melaphyr 230
Organic substance in melaphyr 232
Analyses of dolerite 233
Doleritic lava 235
Composition of dolerite 236
Analyses of altered melaphyr 238
Geognostic features of basaltic cones 238
Basalt in the Eifel 239
Probable origin of basaltic cones 240
Protrusion of lava in fissures 241
Denudation of rocks round basaltic cones 242
Conversion of lava into basalt 243
Grauwacke and clay-slate imbedded in lava 243

PAGE
Basaltic streams in the Eifel 244
Basaltic dykes 245
Basaltic veins 246
Olivine in meteoric stones 246
Analyses of basalt 247
Composition and constituents of basalt 252
Character of the decomposition of basalt 252
Unequal abstraction of bases and silica from basalt 255
Composition of trapp rocks 258
Nephelin in augitic rocks 259
Analyses of nephelin rock 260
Natrolite in basaltic amygdaloids 261
Decomposition of basaltic rocks under different circumstances 262

CHAPTER LV.

HORNBLENDE ROCKS.

Varieties of rocks containing hornblende 264
General character of hornblendic rocks 265
Hydrated minerals in syenite 266
Composition of hornblende rocks 267
Mineral constituents of hornblende rocks 268
Species of felspar in hornblende rocks 269
Diorite of Corsica 272
Constituents of diorite 273
Diorite of the Vosges 274
Analyses of felspar in hornblende rocks 278
Occurrence and characters of syenite 279
Varieties of syenite 280
Minerals in syenite 281
Species of felspar in syenite 282
Constituents of syenite 283
Sequence of production of minerals in syenite 284
Analyses of syenite 286
Analyses of hornblendic porphyry 287
Hornblende-slate 288
Analyses of hornblende-slate 289
Quartzose hornblende-slate 291
Thin veins of syenite in melaphyr 292
Species of felspar in hornblende rocks 297
Greenstone 298
Prehnite in hornblende rocks 299
Varieties of greenstone 300
Felspar in euphotide 301
Alteration and decomposition of hornblende rocks 302
Conversion of hornblende-slate into chlorite-slate 303
Mineral deposits associated with hornblende rocks 303
Metalliferous deposits in the Erzgebirge 304
Limestone associated with diorite 308

PAGE
Metalliferous deposits in Greenland, etc. 310
Conversion of diorite into chlorite-slate 312
Conversion of diorite into talc-slate 313
Bitumen in hornblende rocks 314
Conversion of gneiss into hornblende rock 315
Connection between hornblende rocks, greenstone, and clay-slate 315
Origin of hornblende-slate 317
Chemical features of the alteration of clay-slate 318
Composition of transition slates, as compared with sedimentary rocks 320
Granular limestone associated with slate rocks 324
Relation between clay-slate and syenite 325
Sequence in the arrangement of minerals in syenite 326
Alteration of the silica in clay-slate 327
Characters of schalstone 329
Mineralogical features of schalstone and the rocks associated with it 330
Association of limestone and greenstone 331
Analyses of schalstone 333
Carbonate of lime in schalstone 334
Decomposition of silicate of lime in greenstone 336
Connection of limestone and iron ores 337
Alteration of limestone 338
Removal of carbonate of lime by water 340

CHAPTER LVI.

MICA-SLATE, CHLORITE-SLATE AND TALC-SLATE.

Analyses of mica-slate 342
Relations between mica-slate and clay-slate 346
Analyses of garnet from mica-slate 349
Micaceous constituent of clay-slate 350
Chlorite-slate.... 352
Analyses of talc-slate 352

CHAPTER LVII.

PHONOLITIC AND LEUCITIC ROCKS.

Relations of phonolite to sedimentary rocks 354
Analyses of phonolite 355
Decomposition of phonolitic rocks 361
Conversion of zeolites into felspar 363
Analyses of leucitic rocks 364
Melting point of leucitic lava 367
Connection between phonolitic and leucitic rocks 368

CHAPTER LVIII.

TRACHYTIC ROCKS.

Mineral constituents of trachyte 370
Analyses of trachytic rocks 371

PAGE
Pearlstone and pitchstone 393
Obsidian and pumice-stone 397
Trachytic tuff 404
Puzzolano and trapp 405
Classification of trachytic rocks 406
Alteration of trachytic rocks 407
Production of trachytic rocks from lava 408

CHAPTER LIX.

GRANITIC ROCKS.

Analyses of granite 410
Constituents of granitic rocks 417
Mica in granitic rocks 418
Felspar-porphyry 419
Constituents of porphyry 423
Analyses of granulite and leptinite 426
Relations of granitic and trachytic rocks 428
Connection between limestone and gneiss 430
Silicification of limestone 432

CHAPTER LX.

METALLIFEROUS VEINS—LODES.

Native compounds of metals 433
Origin of minerals in lodes 434
Metals disseminated through rocks 435
Relations of sequence among lode-minerals 436
Association of minerals in lodes 437
Paragenesis 437
Classification of lodes 438
Silicates of metallic oxides 441
Presence of metals in rocks 448
Aluminates 449
Sulphides 450
Conversion of iron pyrites into brown hematite 452
Selenides 476
Antimonides and arsenides 477
Tellurides 479
Titanates 480
Tantalates, niobates, etc. 482
Tungstates 484
Molybdates 487
Chromates 488
Vanadates 489
Antimonates 490
Arsenates 491

PAGE
Carbonates 493
Analyses of iron-spar 496
Deposition of carbonates from water 503
Crystalline form of spathic minerals 504
Phosphates 512
Sulphates 514
Chlorides, bromides, iodides and fluorides 515
Oxides of metals 517
Analyses of manganese ores 522
Native metals 534
Metals in the water of springs 539
Structural characters of lodes 539
Banded structure of lodes 541
Association of minerals in lodes 542
Quartz in lodes 543
Association of quartz with iron ores 544
Relations between lodes and the adjoining rocks 548
Production of ores 552

Index 557

ERRATUM.

Mr. Jukes points out that in the calculation at p. 188, Vol. I., relating to the produce of animalcules the words "millions of" have been omitted after the figures 65,000.

CHAPTER XLIV.

CHEMICAL REACTIONS, RELATING TO THE ALTERATION OF MINERALS.

THE following results have been obtained since the publication of the previous volumes.*

58. The reduction of hydrated peroxide of iron to protoxide by means of decaying organic substance, which is such a frequent phenomenon in nature, may also be effected artificially.†

Experiment I.—Artificially prepared hydrated peroxide of iron, which when dissolved by hydrochloric acid did not give the least trace of blue colour with ferricyanide of potassium, was mixed with a water extract of decayed wood from the centre of an oak tree, and the liquid evaporated to dryness below 212° F. The black residue contained here and there bright particles, which were not attracted by the magnet. When covered with dilute hydrochloric acid, the filtered solution acquired a blue colour with ferricyanide of potassium solution, and, after some time, a blue precipitate was deposited. Consequently, protoxide of iron was present, although not in sufficient amount to produce magnetic oxide of iron. Ferrocyanide of potassium solution added to another portion of the solution, produced a copious blue precipitate; hence undecomposed peroxide of iron was present and to a larger amount than protoxide. Under these conditions, then, peroxide of iron is reduced to protoxide.

Experiment II.—In order to ascertain whether this reduction would take place at the ordinary temperature, though probably more slowly; and also whether it might be facilitated by the presence of carbonic acid, in consequence of the affinity of this acid for protoxide of iron, a current of the gas was passed through the mixture for eighteen hours. The filtered liquid was not coloured blue by ferricyanide of potassium solution. The remainder of the liquid remained out of access of air for twelve days, but still no reaction was produced with this reagent. Hence under these conditions, there is no reduction of peroxide of iron to protoxide.

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* English edition, i, et seq. ii, 57, et seq.

† It is known that a per-salt of iron dissolved in water is reduced to protosalt when sulphuretted hydrogen is passed through the liquid. In this case, it is only the hydrogen of this gas that causes reduction, for the sulphur is eliminated. The affinity of hydrogen for the oxygen in peroxide of iron is sufficiently great to effect the decomposition of the sulphuretted hydrogen. This shows the facility with which peroxide of iron is reduced to protoxide.

Experiment III.—As it seemed probable that the reduction of peroxide of iron to protoxide by organic substances took place only when the latter were in a state of active change; a piece of pig's bladder was immersed in the remainder of the liquid used in the previous experiments. After nine days, the extremely offensive smell of the liquid showed that the organic substance was in a state of advanced decomposition. A portion of this liquid when filtered was rendered green by ferricyanide of potassium solution, but no blue precipitate was produced even after the lapse of some time.

After twenty-four days, it appeared that more protocarbonate of iron had passed into solution; for ferricyanide of potassium solution produced a dark blue colour.

The remainder of the liquid was then analysed quantitatively. The filtered liquid amounted to 12,200 grs., and contained 1·022 grs. peroxide of iron, equivalent to 1·481 grs. carbonate of iron. The insoluble residue, consisting of the undissolved organic substance, and the remainder of the hydrated peroxide of iron, contained 3·194 grs. peroxide of iron, and 0·319 protoxide of iron. This latter amount, together with the 0·920 grs., protoxide dissolved as carbonate, gives 1·239 protoxide of iron, equivalent to 1·377 peroxide of iron. Hence of the peroxide taken:—

1·377	or 30·12	per cent. was reduced; and
3·194	or 69·88	per cent. was not reduced
4·571	100·00	

There is no doubt that in the course of time the whole of the hydrated peroxide of iron would be reduced by contact with the decomposing organic substance.

If, therefore, organic substances are in a state of active change, they effect the reduction of peroxide of iron at the ordinary temperature. Since nitrogenous substances decompose in this way much more rapidly than others, they act most efficaciously. But although, owing to this circumstance, animal substances are particularly adapted to produce this effect, still vegetable remains would have the same influence, though more slowly, for these latter always contain some nitrogenous constituents.

The production of carbonate of iron in water solution, where organic remains and carbonic acid act upon hydrated peroxide of iron, may therefore be understood without any difficulty.

59. The reduction of persilicate of iron to protosilicate, and its conversion into carbonate of iron by decomposing organic substances is a change which is undoubtedly of frequent occurrence in nature, and may also be effected artificially.

Persilicate of iron, precipitated from solutions of perchloride of iron and silicate of soda, was mixed with water, and a piece of bladder membrane added. By the next day a faint odour was perceptible, and the liquid appeared somewhat greenish. In order that there might not be a deficiency of organic substance, a solution of gum-arabic was added. The bottle was closed and inverted in water so as to obviate any possible oxidation by atmospheric air, and from time to time it was shaken, so as to distribute the persilicate of iron through the liquid, and bring it in contact with the membrane. Meanwhile, the green colour of the clear liquid increased sensibly.

At the end of twelve days, the bottle was set aside for the liquid to clear, and when opened, gave out an offensive stink. A portion of the blackish-green liquid, mixed with some hydrochloric acid, acquired a dark blue colour with ferricyanide of potassium solution, and soon afterwards a blue precipitate separated. Hence protoxide of iron had been produced, and dissolved as protosilicate, or as carbonate of iron.

The bottle was again inverted in water for seventeen days. During this time the liquid became milky; it was poured off and 10,000 grains taken for analysis.

A portion of this liquid was heated in a retort with the beak dipping into baryta water. On boiling the liquid, a considerable precipitate of carbonate of baryta was produced, showing that much carbonic acid was generated by the decomposition of the organic substance.

This portion of the liquid was evaporated together with the remainder to dryness; the residue heated to whiteness, melted. It was then digested with hydrochloric acid and some nitric acid, the undissolved portion collected upon a filter, and washed. Ammonia separated from the filtrate 1·173 grs. peroxide of iron.

The residue upon the filter was black; after intense ignition with access of air, the carbonaceous portion originating from the decomposed organic substance burnt, and there remained 1·065 grs. silica, which was almost white and only faintly yellow, showing that it did not contain more than a trace of iron.

It had been shown by the absence of reaction with ferrocyanide of potassium, that the iron in the water solution, was, for the most part, in the state of protoxide. Its amount might have been about 1·056 grs. or nearly as much as the silica. As the liquid contained much carbonic acid, it is improbable that the whole of the protoxide of iron was in the state of silicate, some portion was dissolved as carbonate.

It follows, from these investigations, that decomposing organic substance, in the presence of carbonic acid, reduces hydrated peroxide of iron to protoxide, and also persilicate of iron to protosilicate and carbonate of iron. Further, that nitrogenous substances are more adapted to produce this result, since they decompose most rapidly. Whether the reduction of hydrated peroxide of iron takes place in the absence of carbonic acid was not determined; but since carbonic acid is produced by this reduction, it is probable that it would commence even in its absence. This is the more probable, since in the reduction of prosilicate of iron, carbonate of iron is produced, together with protosilicate.

The reduction of hydrated peroxide of iron, and of persilicate of iron, is of great importance as regards geology. The protosilicates of iron in the crystalline and amorphous rocks, are subject to a constant oxidation, which in fact determines their decomposition. If there was not a process of reduction going on also, the whole of the protosilicates of iron would in course of time disappear.

It is not known whether there is any other means of reduction concerned in the alteration of minerals. If organic substances are the only reducing agents, there could not have been any reduction of peroxide of iron prior to the appearance of organic structures on the earth. However the considerable amount of carbon to which the black colour of some slates is due, shows that even at the time when the slates, destitute of organic remains, were produced from ocean deposits, there was an abundance of reducing substance in existence.

The blue clay constituting the undermost layer of the silurian, series in West Russia is full of algæ.* Its blue colour indicates a considerable amount of protosilicate of iron, and admits of the inference that these organic remains were the means of reducing the persilicates of iron, or at least of preventing the oxidation of protosilicates. From these rocks—the oldest bearing organic remains—through all intermediate series to the most recent sedimentary deposits, petrified remains are found, and consequently there have been means of reducing the compounds of peroxide of iron. Even in the sand-stone, covering the blue clay, the *obolus* occurs in great abundance, the remains of which, according to the above results, would have favoured the reduction, still more than vegetable remains.

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* Eichwald—Bullet. de la Soc. impér. des Naturalistes de Moscou. xvii. 4.

Consequently, where protosilicates of iron are met with in sedimentary rocks, or in crystalline rocks that have originated from these by a process of metamorphosis, and associated with organic remains, this circumstance justifies the inference that the latter have effected the reduction, or at least prevented the oxidation of the protoxide compounds. Moreover, in this reduction, may be recognized an essential element of the conversion of amorphous masses into crystalline rocks.*

The various possible modes in which green earth may originate have already been pointed out.† The facts just referred to point to another mode by which this mineral may be produced, and this is the more important, since its very abundant and frequent occurrence in the most diverse old and recent sedimentary rocks, even to those of the silurian series, admits of the conjecture that it has been produced in all cases in the same way. Every clay containing a predominating amount of persilicate of iron, and silicates of alumina, magnesia and alkalies, together with organic remains may be regarded as material for the production of green earth.

60. The carbonic acid absorbed by water is entirely displaced by atmospheric air. The unequal displacement of gases absorbed by liquids, is known to be a remarkable chemical phenomenon; but it has also no small geological significance, especially the above-mentioned instance.

The displacement of carbonic acid by atmospheric air manifests itself even in the case of water from a carbonated spring exposed in an open vessel; it soon loses its agreeable taste, owing to the escape of carbonic acid. In order to ascertain the length of time that this change takes when the water is brought into intimate contact with atmospheric air, the following experiment will suffice.

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* See chap. xlviii—Metamorphic rocks.

† English edition, ii. 132.

Atmospheric air was passed through water saturated with artificially prepared carbonic acid. A glass tube, connected with a gasometer, passed to the bottom of the glass vessel containing the water, the air issuing from three small holes. At the same time an equal quantity of carbonated water was placed in another open glass during the experiment. The difference between the amount of carbonic acid remaining in the one quantity of water, and that in the other after the experiment, gives the quantity of carbonic acid displaced by atmospheric air passed through the one portion of water. The amount of carbonic acid was estimated in both instances by means of baryta water. Eight ounces of water was used in both instances, and the results were reduced to 1,000 parts of water.

Duration of the current of air.	Residual carbonic acid in the water through which air was passed.	Residual carbonic acid in the water simply exposed to the air.
I. 15 minutes.	0	3·785
II. 5 minutes.	0·268	3·940
III. 7½ minutes.	0	not estimated.

It appears, therefore, that when atmospheric air is passed through carbonated water for five minutes, there remains only 0·068 per cent. of carbonic acid in the water. When the air is passed through for 7½ minutes, all the carbonic acid is displaced.

The carbonated water contained in 1,000 parts—

Experiment I. 9·86 carbonic acid.
 „ II. 10·26 „

The carbonic acid combined with carbonate of lime as bicarbonate, in water is also displaced by a continued current of atmospheric air, and the carbonate of lime precipitated.

In the following experiments, solutions of bicarbonate of lime were used, prepared by passing carbonic acid for twenty-four hours through water mixed with carbonate of lime.

Experiment I.—A gives the composition of such a solution. B gives the composition of the same solution after atmospheric air had been passed through it for 7½ minutes.*

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* The carbonic acid of the bicarbonate, and the free carbonic acid was precipitated as well as the lime, as neutral carbonate by means of baryta water. The precipitate was washed in a covered glass as long as the filtrate contained baryta, so as to prevent precipitation of baryta as carbonate, by atmospheric carbonic acid. It was then dissolved by hydrochloric acid, the solution diluted with enough water to retain the sulphate of lime in solution, when the baryta was precipitated with sulphuric acid. In the filtrate from the sulphate of baryta, the quantity of sulphate of lime was estimated.

10,000 parts of solution.	A.	B.
Neutral carbonate of lime	5·703	5·729
containing carbonic acid	2·503 ...	2·514
Additional carbonic acid of bicarbonate of lime, and free carbonic acid ...	17·790 ...	2·874

As 17·790—2·874 = 14·916, it follows that in A there was

Carbonic acid of carbonate of lime	2·503
" bicarbonate " ...	2·874
Free carbonic acid	14·916
	20·293

According to general opinion, the carbonate of lime dissolved in water exists in the state of bicarbonate; but according to the above experiments, the amount of carbonic acid over and above that in the carbonate of lime is somewhat greater than that of the carbonate: consequently, it would appear that a current of atmospheric air passed through a solution of bicarbonate of lime containing free carbonic acid for 7½ minutes is not sufficient to displace the latter completely.

Experiment II.—Another solution was used consisting of bicarbonate of lime through which carbonic acid had not been passed so long as in the former experiment. A, gives the composition of this liquid. B, gives the composition after air had been passed through the liquid for 15 minutes—

10,000 parts of solution.	A.	B.
Neutral carbonate of lime	3·698	—
containing carbonic acid	1·623 ...	—
Additional carbonic acid of bicarbonate of lime, and free carbonic acid	10·103	1·631

As 10·103—1·631 = 8·472, it follows that in A there was:

Carbonic acid of carbonate of lime	1·623
" bicarbonate	1·631
Free carbonic acid	8·472
	11·726

In this instance, the quantity of carbonic acid in the carbonate of lime, and that of the additional acid in the bicarbonate, are what they should be. Consequently, the acid carbonate of lime in solution was really a bicarbonate.*

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* It is not improbable that the production of bicarbonate of lime in a solid state is impossible, on account of the affinity between carbonic acid and water being greater than that between it and carbonate of lime. If this were not the case the additional equivalent of carbonic acid would not be separated with the water evaporated, or displaced by atmospheric air, but would remain combined with carbonate of lime as bicarbonate.

Since the solution of bicarbonate of lime reddens litmus paper considerably, before air is passed through it, while the liquid through which air has been passed does not do so at all, it follows that the additional equivalent of carbonic acid does not exercise an acid reaction, and hence it may be appropriately termed half-combined. Since, moreover, the solutions through which atmospheric air had been passed for 7½ and 15 minutes, were not rendered in the least turbid, it is evident that within this time, only the free carbonic acid was displaced.*

In the Experiments I. and II., the amount of free carbonic acid was 5·19 times as great as that of the additional carbonic acid in the bicarbonate of lime; however, it must not be overlooked that in Experiment I. the latter was estimated somewhat too high, and the former rather too low. But it is evident that water dissolves the maximum amount of bicarbonate of lime only when it is perfectly saturated with carbonic acid, provided that enough neutral carbonate of lime is present.

The largest amount of carbonate of lime that I have found † in the mineral water saturated with carbonic acid, in the neighbourhood of the Lake of Laach, is from 5·1538 and 6·1389 parts in 10,000 parts of water, being pretty nearly the same as in the artificially prepared water used in Experiment I. In other kinds of mineral water, also saturated with carbonic acid, the amount of carbonate of lime is sometimes as low as $\frac{1}{10,000}$.

In the brine saturated with carbonic acid at Neusalzwerk, I found 8·686 carbonate of lime in 10,000 parts of water.‡ As this quantity far exceeds the above maximum, it cannot be ascribed to any other cause than the presence of an excess of carbonate of lime at the place where this brine is formed, while this is not the case where the above-mentioned mineral springs take their origin. This is really the case; for the brine from the 2,210 feet boring at Neusalzwerk springs from shelly limestone,§ while the above-mentioned springs rise from clay-slate, in which carbonate of lime does not exist, but is produced only by the decomposition of silicate of lime by means of carbonic acid.

Experiment III.—When atmospheric air was passed for 32 minutes through a solution of bicarbonate of lime, a slight turbidity was produced, and after 12 hours a slight precipitate had separated. By a long continued current of atmospheric air, therefore, the carbonic acid combined with carbonate of lime may be partially displaced. The following experiment illustrates this fact:—

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* As a consequence of this fact the amount of free carbonic acid in a mineral water may be easily estimated by passing atmospheric air through it. But, as the following experiment shows, that, by continued passage of atmospheric air, the bicarbonate of lime is decomposed, care must be taken to stop the current of air as soon as the faintest indication of a precipitate appears. The error thus produced is too small to influence the result.

† See German edition, i, 357, et seq.

‡ Ibid. p. 884.

§ See German edition, i, p. 155.

Experiment IV.—After passing atmospheric air for 32 minutes through 10,000 parts of a solution of bicarbonate of lime, a scarcely perceptible precipitate was produced; but it was increased somewhat by passing the air through for 41 minutes longer.

The decanted liquid was, however, quite clear, though the sides of the vessel were covered with an extremely thin crust of crystalline carbonate of lime, amounting to 0·596 grs. In the clear liquid, there was 2·352 grs. in solution. Consequently, there was nearly one-fifth of the carbonate of lime, originally dissolved in the water, precipitated by atmospheric air.

In order to ascertain whether this precipitation might perhaps arise from evaporation of water while the current of air was passed through the solution, the following experiment was made.

Experiment V.—The solution of bicarbonate of lime was weighed, and after a current of air had been passed through it for 30 minutes, a slight turbidity began to appear; after the current of air had been continued for 55 minutes, 20 parts of water had evaporated from the 10,000 parts. The sides of the glass vessel in contact with the liquid, and the bottom were covered with a very thin crust of carbonate of lime, amounting to 1·654 grs. The decanted liquid was scarcely turbid. After 24 hours, some more carbonate of lime had been deposited at the bottom of the vessel; but the liquid was still clear.

After an additional 2·3 cubic feet[*] of atmospheric air had been passed through the liquid, the sides of the vessel were again coated with a crust of carbonate of lime, amounting to 0·965 grs.

The liquid filtered from this deposit was not again treated with air, and during the night a small quantity more carbonate of lime was deposited. The quantity of lime remaining in it was then estimated by means of oxalate of ammonia, and found to be 3·130 grs.

The several deposits of carbonate of lime amounted to 2·619 and there
remained in solution .... 3·130
5·749

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[*] Before this experiment the quantity of air passed through the solution was not measured; but after this it was estimated from the cubic contents of the gasometer=1·15 cubic feet.

Therefore, the lesser portion of the carbonate of lime in solution was precipitated by the current of atmospheric air. As the 10,000 parts of solution contained 5·749 parts carbonate of lime, the 20 parts of water evaporated during the passage of air through the solution for 85 minutes would be equivalent to only 0·011 carbonate of lime. But during this time 1·654 parts of carbonate was deposited, or 150 times as much, so that the evaporation had very little influence upon this deposition of carbonate, which was chiefly due to the displacement of carbonic acid by atmospheric air. For estimating the quantity of carbonic acid in the solution through which no air had been passed, it was mixed with baryta water; the precipitate of carbonate of baryta decomposed by sulphuric acid gave 34·334 sulphate of baryta, corresponding to 6·480 carbonic acid existing in a free state, and in combination with carbonate of lime as bicarbonate.

Then since this 5·749 carbonate of lime corresponds to 2·523 carbonic acid contained in it and an equal quantity combined with it in the state of bicarbonate, the quantity of free carbonic acid would amount to 6·480—2·523 = 3·957.

Therefore, the solution contained in 10,000 parts:—

Carbonic acid in carbonate of lime	2·523
Additional carbonic acid in bicarbonate of lime ...	2·523
Free carbonic acid	3·957
	9·003

Consequently, the solution contained almost exactly as much carbonate of lime as that used in Experiment I.; but the latter contained nearly four times as much free carbonic acid as the former. Therefore, so large an excess of free carbonic acid does not increase the quantity of carbonate of lime dissolved; for, in the preparation of both solutions the carbonate of lime was not all dissolved, and remained at the bottom of the vessel. The quantity of additional carbonic acid requisite for solution of the deposit of 2·619 carbonate of lime was 1·149. As the turbidity of the solution did not appear until air had been passed through it much longer than was requisite for the complete displacement of the free carbonic acid, and since then only 0·45 of the additional carbonic acid was displaced, it follows that the affinity between carbonate of lime and the additional carbonic acid in bicarbonate of lime is much greater than that between free carbonic acid and water.

These experiments show, moreover, that the former is less easily displaced in proportion as the amount of bicarbonate of lime in solution decreases. This is also evident from the following experiments:—

Experiment VI.—The water used was taken from the well attached to the chemical laboratory at Bonn, and which, like the water of all wells in the alluvial deposits of the Rhine district, is derived from the Rhine. This water contained, in 10,000 parts, 3·254 neutral carbonate of lime. The free carbonic acid, and that combined with carbonate of lime as bicarbonate, was precipitated by means of baryta water, and amounted to 2·82 parts. When atmospheric air had been passed for 15 minutes through this water, it was found to contain 2·17 carbonic acid, which was combined with carbonate of lime as bicarbonate; for, according to the previous experiment it may be assumed that, within the 15 minutes, all the free carbonic acid, would be expelled by atmospheric air. The 3·254 carbonate of lime in this water contain 1·428 carbonic acid, and as much carbonic acid as will be combined with it in the state of bicarbonate. But, since the quantity found, was 2·17, or 0·742 more than that, the excess would be owing to the presence of magnesia existing in the water, together with carbonate of lime.

Experiment VII.—Through 10,000 parts of the same well water 19·8 cubic feet of air was passed, but without any turbidity being produced. After decanting the water, however, there was an incrustation upon the sides of the vessel, amounting to 0·49. After this water, that had been treated with air, had stood two days and a half, the sides of the vessel were covered with a large number of small crystals of carbonate of lime, amounting to 0·374 grains.

It appears, therefore, that by passing air through this water the carbonate of lime separated in minute crystalline particles that remained long suspended in the water, and were only gradually deposited upon the sides and bottom of the vessel. As these small crystals are transparent, they cannot be perceived in the same way as the particles of carbonate of lime that are produced when an alkaline carbonate is added to a solution of a lime salt, for these latter are amorphous, and may, therefore, be seen even in very dilute liquids.

Experiment VIII.—The previous experiment was repeated for the purpose of estimating the quantity of water evaporated during the passage of the 14·2 cubic feet of air.

This evaporation amounted to 59 parts in the 10,000 of water, and therefore could not have exercised so great an influence upon the deposition of carbonate of lime as in the Experiment V. For if 4,343 parts of this water evaporated, even then the solution of carbonate of lime would have been only as concentrated as that used in Experiment V. Certainly if, during this evaporation, the carbonic acid combined with the carbonate of lime as bicarbonate were separated, a deposition of carbonate of lime would result.

In this experiment the quantity of crystalline carbonate of lime deposited was only 0·251, which corresponds with the fact that, in this instance, only 0·72 times as much air was passed through the water as in Experiment VII.

When the water remaining from this and the previous experiment had stood for several days in open vessels, a further deposit was produced on the sides of the vessel when the water was in contact with the air, and a film appeared upon the surface. These deposits could not have been the consequence of evaporation, but were only due to the progressive exchange of carbonic acid combined with carbonate of lime as bicarbonate for atmospheric air. Such deposition from this cause would continue until the liquid had reached the point of saturation by evaporation. After that point was reached, carbonate of lime would be deposited in consequence of further evaporation. Therefore there is this difference between the deposition of carbonate of lime and that of other salts, that the latter can be deposited only from saturated solutions, while the former may be deposited from solutions that are not saturated, in consequence of the displacement of carbonic acid from bicarbonate of lime by atmospheric air, so long as the solution has not attained its point of saturation.

Experiment IX.—Through 10,000 parts of Rhine water, 11·3 cubic feet of atmospheric air was passed; but no trace of a deposit appeared. When the water was left standing in an open glass for several days, a deposit could be distinctly perceived upon the sides of the vessel at and under the surface. This shows that even from so dilute a solution of carbonate of lime, containing only 0·14 to 0·9 in 10,000 parts, this deposition of carbonate may take place owing to the action of the atmosphere.

The above investigations furnish an additional means of accounting for the deposition of carbonate of lime even from very dilute solutions. The fact which they demonstrate has great importance for geology, and admits of the explanation of the production of limestone deposits from the sea, and from lakes or rivers, as will be more particularly shown in treating of sedimentary limestone.

61. The carbonic acid, combined with carbonate of iron, in water, is quickly displaced by atmospheric air passed through the solution. In this case two actions are combined:—the higher oxidation of the oxide of iron, by atmospheric oxygen, and the displacement of carbonic acid combined with the carbonate of iron. The former action is by far the preponderating one; and hence it comes that deposition of hydrated peroxide of iron takes place rapidly and completely, while the deposition of carbonate of lime effected merely by displacement of the carbonic acid combined with it, goes on but slowly and incompletely.

Although the rapid deposition of hydrated peroxide of iron from ferruginous acidulated water when exposed to the air, is a well-known phenomenon, still the following experiments were made by passing air through such water:—

Experiment I.—An artificially prepared solution of bicarbonate of iron was exposed for 7½ minutes to a current of atmospheric air. A milky turbidity, with a tinge of yellow-brown, was produced. Baryta water precipitated an ochre-coloured precipitate; while, from a solution through which no air had been passed, it gave a white precipitate, which soon became ochre-coloured.

Experiment II.—Another freshly prepared solution of bicarbonate of iron that did not redden litmus, was subjected for 30 minutes to a current of atmospheric air. The oxide of iron was thereby so completely precipitated, that neither ammonia nor ferrocyanide of potassium gave the slightest reaction with the filtered liquid. The precipitate was not fully deposited until after the lapse of 24 hours. The amount of oxide of iron was 0·37 in 10,000 parts of water.

Another solution, through which no air had been passed, gave with baryta water, a precipitate that was, for the moment, white, but soon became a dirty green and ochre-coloured. The oxide of iron precipitated amounted to 0·448 in 10,000 parts of water, so that it was rather more than in the previous instance.

By comparing these results with those of the experiments with carbonate of lime, it appears that the carbonate of iron is completely precipitated before the carbonate of lime begins to be deposited. Therefore, when both these carbonates are present in water subject to the action of atmospheric air, the iron will be first deposited as hydrated peroxide, and completely separated from solution before the deposition of the carbonate of lime commences.* Thus, in the deposits from the water of springs, the deposition of oxide of iron always precedes that of carbonate of lime, except when the springs furnish hot water, in which case a part of the carbonic acid combined with the carbonate of lime as bicarbonate is also separated together with the water evaporating, and some carbonate of lime is consequently deposited together with the oxide of iron, or as at the Carlsbad springs, they are deposited alternately. In the case of cold springs, also, it may happen, that when the water is very rich in carbonate of lime, and when it stagnates, after issuing from the spring, the oxide of iron deposited is mixed with some carbonate of lime. Since, however, the iron ochre deposits from cold springs either do not effervesce at all with acid, or only to a slight degree, it follows that the deposition of iron always precedes that of carbonate of lime.

This behaviour of these substances shows how beds of brown hematite may originate by deposition from water containing bicarbonate of lime, without the hematite being mixed with carbonate of lime at all, or only in a small amount.

62. Silica is precipitated from a solution of silicate of soda in carbonated water, by carbonate of lime. This is proved by the following experiment:—

A perfectly transparent rhomboid of calc-spar, weighing 166·45 grs., was put into a large bottle filled with distilled water, saturated with carbonic acid, and containing 33·3 grs. of silicate of soda in solution. The bottle was closed and left for 17 months and 12 days. As the carbonic acid partially decomposed the silicate of soda, it was possible that the precipitated silica might displace a portion of the calc-spar. At the end of the time named, a number of green confervæ had been produced in round particles, which covered the bottom of the bottle. The faces of the crystal had entirely lost their lustre, and become dull, the crystal being only translucent. The liquid was evaporated to dryness; the residue effervesced with acids, but contained only 0·042 grs. of carbonate of lime. This effervescence, therefore, arose chiefly from carbonate of soda.

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* This difference in the behaviour of these carbonates, which are often present in the water of acidulated springs, may be taken advantage of in the analysis of such water by passing a current of air through it for at most 30 minutes, for the purpose of precipitating the oxide of iron. When great accuracy is required, the precipitate must be tested to ascertain whether it contains carbonate of lime. This method has the advantage that alumina, when present in a mineral water, would be separated from iron since that earth is not precipitated by air.

The crystal was laid in water and, from time to time, a few drops of hydrochloric acid were added. It was easily perceptible that the bubbles of carbonic acid rising, carried with them microscopic particles of gelatinous substance. The crystal soon recovered its lustre and transparency. When the escape of gas bubbles had ceased, and the liquid was stirred, the gelatinous particles floated in considerable quantity.

There can be no doubt, therefore, that a coating of silica had been deposited upon the crystal diminishing its transparency; and that the carbonate of lime found in the liquid had been dissolved by the carbonic acid. A portion of the calc-spar had, therefore, been displaced by the silica of the silicate of soda. If the crystal had been immersed in a fresh solution of silicate of soda in carbonated water, and this had been constantly renewed, after a long series of years, the entire crystal of calc-spar would have been dissolved and silica would have been deposited in its place, presenting, most probably, the form of the calc-spar.

Since carbonated water, containing silicate of soda, circulates in rocks, the conditions exist there for the displacement of carbonate of lime by silica in the same manner as in the foregoing experiment. The frequent displacement pseudomorphs of silica with the form of calc-spar * may, therefore, have been produced by such a process, and the character of these pseudomorphs corresponds well with such a mode of origin.

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* English edition, i, 479.

CHAPTER XLV.

GENERAL REMARKS ON ROCKS.

AFTER having, in Chapters XVII. to XLIII., treated of the chemical history of minerals, their occurrence, production, displacement, and decomposition, we now come to the consideration of the rocks which constitute the crust of the earth so far as we are acquainted with it. Those minerals only have been treated of which are the most frequent and widely distributed, and those whose chemical history is best known at the present time; and the treatment of rocks will be limited in like manner. All that has been ascertained with regard to the production of minerals, must also apply to the rocks which consist of these minerals.

When the interior of the earth's crust is laid bare by valleys, often many thousand feet deep, a succession of different rocks is met with. This is also the case where portions of the earth's crust is opened up by mining operations or borings. It is quite proper that we should consider the rocks in the same order of succession in which they have been formed; that we should, therefore, commence with the oldest and end with the most recent. As it is not unfrequent, that rocks have been formed by alteration of older rocks, their consideration in the inverse order could not be combined with the investigation of the chemical or genetic relations of rocks; for the knowledge of a rock must be preceded by that of the materials from which it has been formed.

But, it may be asked, which are the oldest rocks, with which to commence our examination? The older geological schools regarded granite, and the rocks allied to it, as the oldest. Later investigations have, however, shown that this view is erroneous. At the present time, we know that going from the surface downwards, it is the stratified rocks, clay slate, micaceous schist, and gneiss, whose underlying strata are unknown, that are the oldest rocks. For the empirical investigator, therefore, these rocks are to be regarded as primitive; that is to say, the initial members of the series of rocks that are the subject of investigation.

Putting aside hypothetical assumptions, it is necessary to regard stratification as an unmistakeable indication of the sedimentary origin of rocks. But such a mode of formation must be ascribed not only to the strata that have been deposited, either mechanically or chemically, by the sea, by lakes, rivers, and springs; but also to those masses which have originated from the decomposition of crystalline rocks, which sometimes present a kind of stratification.

Suspended particles that are deposited from water can only give rise to amorphous deposits. When in such deposits crystalline minerals are found, they can only be regarded as having been produced subsequently. The formation of such minerals may have progressed so far, and to such an extent, as to have given rise to crystalline rocks. If, at the same time, the stratification is not obliterated, the origin of these rocks will be evident. But when this indication of their sedimentary origin is obliterated, as is sometimes the case in the conversion of sedimentary limestone into crystalline limestone, and very frequently in dolomitic rocks, then there remains only one other indication of the sedimentary origin of these rocks, namely, the presence of organic remains, either as still recognizable forms, or carbonaceous substances. Schafhäutl,* indeed, found in the Bavarian Alps red marble, consisting almost entirely of ammonite shells; and Goldfuss has informed me that the dolomite of Gerolstein in the Eifel is as rich in fossils as the adjoining limestone. When fossils are wanting there may be graphite, which, in crystalline limestones, is not only the cause of the dark bluish-grey colour of some varieties, but also occurs as imbedded laminæ or granules in the white varieties.

The adherents to Plutonistic views call the stratified crystalline rocks, metamorphic; a term which is quite appropriate, and which I shall also adopt as distinctive of such rocks, although with regard to its signification, as regards the nature of the metamorphic processes, my views are entirely at variance with those of the Plutonic school.

For rocks which contain crystalline minerals, the term crystalline rocks is certainly the most appropriate, since it denotes the character of those rocks without reference to their mode of origin. This term is also applicable to the metamorphic rocks, as well as to those rocks which do not present stratification, or contain organic remains, the indications of sedimentary origin. The Plutonists call crystalline rocks "plutonic," as if a term based upon an unfounded hypothesis was sufficient to make such an hypothesis true.

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* Jahrbuch für Mineral. etc., 1846, p. 645; and 1848, p. 137.

In conformity with the above remarks, I shall in the succeeding chapters commence with the consideration of the sedimentary rocks, and then go on to the crystalline and metamorphic rocks. In the Chapters XLVI., XLVII., and XLVIII., these rocks will be treated of generally, and in the following chapters in detail. Drusy cavities and dykes or veins will be treated of in a separate chapter, and this will also be the case with the metalliferous veins or lodes. The volcanic rocks, that is to say, the masses that have evidently issued from the centres of volcanoes, either within, or prior to, the historic period, will form the conclusion of the work.

CHAPTER XLVI.

SEDIMENTARY ROCKS.

Occurrences.—THE sedimentary rocks are the most frequent of all, and much more abundantly met with than the crystalline rocks.

Formation.—Sedimentary rocks must be regarded as originating from substances carried into the sea by rivers. Material is also furnished by the disintegration of coasts by the action of the sea.

Sedimentary rocks, that were originally horizontal, are frequently found situated at a greater or less incline, or even in a vertical position, in consequence of elevations and depressions, and the same causes have given rise to a great variety of other conformations. These dislocations can have taken place only after the strata had acquired a certain degree of conglomeration and hardness by the cementation of their particles.

The generality of strata present a more or less distinct structure, which, in most cases, is parallel to the planes of stratification. But in many schistose rocks, especially in clay slate, and grauwacke slate, the slaty structure, and the cleavage, are not parallel with the stratification, but intersect it at an angle varying from a few degrees to a right angle. In such cases, therefore, besides the original parallel structure, an entirely new parallel structure has been developed, which is often much more perfect than the other, so that the original parallel structure is much less prominent than this secondary slaty structure, and is, indeed, sometimes entirely concealed by it. This phenomenon may not unfrequently be traced through entire mountain ranges, and it appears to be quite independent of, and unconnected with, stratification. In the case of strata that undulate, while the slaty cleavage is at the same time, rectilinear, this independence is very distinctly recognizable. Since the secondary slaty cleavage is in no way connected with the extension and situation of the strata in which it is apparent, it would appear that it has originated long after the deposition of the materials from which the strata were formed. The entire independence of this slaty cleavage, and the conformations produced by dislocations, prove, moreover, that it must have originated subsequent to these dislocations.

This phenomenon is met with almost exclusively in the oldest rocks, and those belonging to the clay slate series which have experienced dislocation most largely; but in many cases the slaty cleavage is parallel with the plane of stratification. In the strata of the more recent sedimentary rocks, and in crystalline rocks, slaty cleavage is very rarely met with. According to Darwin, the thick and extended slate-beds belonging to the chalk series in Terra del Fuego, is an exception to this rule.

Geologists have put forward several hypotheses, mostly untenable, for the purpose of explaining this remarkable phenomenon. Thus, for instance, Naumann* remarks, that when we remember that slaty cleavage is met with only in strata that have been much dislocated, that it is generally parallel with the dip of those strata, so that its inclination, like that of the strata, is parallel with the main line of dislocation, it appears evident that there is some connection between these conditions of structure, and the great motive agencies and lateral pressure prevailing while these strata were being formed. I agree with Naumann, in regarding as very probable the view first put forward by Baur,† that the secondary or transverse slaty cleavage is the result of a transposition of the original parallel laminar structure, by violent lateral pressure exercised while the mass of the strata was still somewhat soft and had some degree of mobility. This transposition consisted essentially in the ultimate particles of the slate placing themselves at right angles to the direction of the pressure.

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* Lehrbuch der Geognosie, i, 999.

† Archiv für Mineral. etc., xx, 351, 1846.

Daniel Sharpe[*] was led, by a consideration of the connection between the elongation and compression of fossil remains, and the situation of slaty cleavage, to adopt the opinion that the mass of these strata must have been subjected to compression acting at right angles to the plane of slaty cleavage; and he also inferred that, at the same time, there was an expansion, or elongation of the strata in the direction at right angles to that plane, by which that compression was compensated. John Tyndall[†] has shown that no slate ever exhibits so clean a cleavage as a mass of pure white wax, submitted to pressure, which, by splitting into laminæ of surprizing tenuity, proves that pressure is sufficient to produce cleavage; and that this cleavage is independent of the intermixed laminæ of mica, as assumed in Mr. Sorby's "theory of slaty cleavage." I am the more disposed to agree with this observation, from the circumstance that I shall, subsequently, have occasion to disprove the existence of laminæ of mica in the sediment from which slate rocks have been formed.

The particles of solid substances suspended in the water of rivers which form deltas,[‡] are deposited there, and are thus concentrated within a comparatively small space. In the case of rivers that have no deltas, the suspended particles are distributed in the sea over such an extent as the currents of the tides extend.[§]

These currents are regular and periodical, while those caused by shifting winds are varying.

Deltas are sedimentary formations in a bay of the sea; such as those of the Mississippi, Ganges, Burrampooter, and the rivers that fall into the Mediterranean, which is nothing more than a large bay of the sea. Generally these deposits are comparable with those formed in lakes, with the exception that the suspended substance is deposited more rapidly in the less dense fresh water than in the denser salt water of the sea. The further the mouths of a river advance by delta formation, the further will the substances suspended in their water be carried into the sea. The finer particles of previous deposits will be swept away mechanically by the surf, and again deposited at a greater distance from the land. The separation of finer and coarser particles that has not been effected in the deltas, will, therefore, be effected in this way. At the time when the rivers are flooded, and their water runs far into the sea, coarser particles will be deposited upon layers of finer materials in the deltas; and, in this way, an alteration of clay and sandstone strata will be produced.

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[*] Quart. Journ. of the Geol. Soc., 1847, p. 87, et seq.

[†] Phil. Mag., July, 1856.

[‡] English edition, i, 169.

[§] This subject was thoroughly treated of by De la Beche, in his Geology (Edited in Germany, by Dieffenbach, 1852, pp. [illegible]3-107.) I regret that I am unable to coincide with him in many of his opinions, so far as they relate to chemical details.

Between New Orleans and the sea, the Mississippi has a fall of only one inch and a half in the mile, and when its water is low the fall within this distance of about one hundred miles is barely perceptible. This river can, therefore, carry only the finest particles of suspended substance into the sea, and can only give rise to the formation of clay deposits. According to Lyell's estimate the delta of the Mississippi has a thickness of 528 feet and extends over a surface of 13,600 statute miles.*

The apex of the delta of the Ganges and Burrampooter is in a direct line 220 miles distant from the sea, and its base, including both arms of the stream, is 200 miles long. At the time when the water of these rivers is low the tides extend to the heads of the delta; but when during the rainy season the rivers are flooded their velocity acts against the flood-tide, which is then observable only near their mouths.† Both these rivers which flow for such a distance through their delta with so slight a fall, cannot transport coarse gravel, but carry into the sea only finely divided substances. According to Rennel's observations, during eleven years' stay in India, the mouth of the Jellinghy advanced one eighth of a mile.

There are dates relating to the prolongation of the delta of the river Po, extending back as far as the twelfth century, and obtained by the investigations of Prony. From 1200 to 1600 it amounted on the average to 75 feet annually. Since the last 200 years, however, it has been 210 feet.‡

The Niger, like the Ganges, shows a delta formation under the influence of the tides. In the case of this river, as with many other tropical rivers, mangrove trees contribute essentially to this effect. Wherever they find protection they grow in great numbers; the suspended substances becomes entangled in their roots and form a nucleus for further deposition.§

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* Principles of Geology, 7th edit., p. 218.

† Account of the Ganges and Burrampooter, by Rennel—Phil. Trans. 1781. —Lyell, loc. cit.

‡ Cuvier—Sur les Révol. du Globe.

§ De la Beche—loc. cit, p. 84.

If the periodical currents caused by the tides predominate in such a degree that the rivers even when flooded offer no opposition to sea water, the so-called negative deltas or estuaries are formed. Not only is there no extension of the land in this case, but the sea progressively encroaches during the flood tides, overflows the coasts, washes away deposits and land, and the ebb tides carry this substance away with the suspended substance of the river.

Large rivers, when they are flooded and turbid, carry their suspended substances into the sea to a considerable distance. Thus, Sabine found turbid water at a distance of fifty miles from the mouth of the Amazon.

Lake Superior shows how far suspended substances may be carried into the sea by the influence of wind.* Parts of the sea-bottom, of as large superficial extent as the whole of England, may therefore be covered with mechanical deposits of the same or similar kinds, merely by this means; and, consequently, sedimentary strata of this extent may be formed. But in the ocean there is in the periodical currents caused by the tides, a still more powerful means of diffusing mechanically suspended substances. The suspended substances held back, or even driven back, in rivers during the flood tide, will be carried far into the sea during the ebb tide as if by a prolongation of the river's course, and deposited at great depths. The suspended substances carried into the sea by the Seine and other French rivers falling into the English Channel, will, probably, not be deposited nearer than the coasts of Scotland.

From the time that the height of the periodical flood tides falls to a minimum, to the time when it rises to a maximum, we may suppose that there is a gradual transition from mechanical deposition to a deposition by means of organic action; for, although little is known as to the conditions under which the marine animals that excrete calcareous substances, carry on their work, still the circumstance that carbonate of lime is rarely a constituent of mechanical deposits, shows that when the conditions are most favourable for the former, they were most unfavourable for the latter class of deposits. On the other hand, the corals flourish best in open water that is constantly agitated, where the conditions for mechanical decomposition are the most unfavourable.†

The depth at which deposition of finely divided substances may be again disturbed, extends during the prevalence of violent storms to about sixty feet generally. On the banks of Newfoundland the action of the waves is said to extend to five hundred feet,* and at St. Giles to as much as five hundred and seventy-eight feet. Therefore deposits that had been formed at these depths during a calm sea would be again removed and deposited at other parts of the sea bottom.

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* English edition, i, 118.

† Ibid. i, 172.

Not only do rivers carry into the sea material for the formation of sedimentary deposits, but the surf also acts with considerable force upon the coasts, and contributes largely to this result.

The thicker sedimentary strata are, and the greater their continuous extent over portions of the continent, the less is it possible to refer their formation to deltas, and the more necessary is it to assume that they have been produced by currents in the ocean. If it is admissible to take the analyses of the substances suspended in the water of rivers as a guide, they would not give rise to deposits differing in any important particular, whatever might be the river from which those substances were derived, for the composition of these substances always corresponds with the different varieties of clay-slate and grauwacke, both of which, and especially the former, originate only from the finest particles of those suspended substances. This applies also to the substances abraded from the coasts by the action of the waves, and the substances suspended in sea water.

Comparing the amount of suspended substances in the water of rivers with that of the carbonate of lime dissolved in it, and which furnishes the chief material for the formation of deposits by organic action, we find the following relations:—‡

	Suspended Substances.	Carbonate of lime.
Rhine, when much swollen and turbid, 24th March, 1851	1	0·15
„ when very low, and the water of ordinary clearness 27th March, 1852	1	9·80
Elb, 1st June, 1852	1	7·80
Danube, 5th August, 1852	1	0·90

By adding to the dissolved carbonate of lime that contained in the suspended substances, and deducting this carbonate of lime from the latter, the relation becomes as follows:—

	Suspended Substances.	Carbonate of lime.
Danube	1	1·5
Vistula, 4th March, 1858 ...	1	2·0
Thames, in 4 analyses	1	5·5 to 15·57
Möll	1	4·4
Oetz	1	0·5

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* Emy. Sur les travaux hydrauliques maritimes.

† Siau—Poggend. Ann., lvii, 598.

‡ English edition, i, 76 and 123.

Taking into account only those rivers that flow directly into the sea, it appears that in the Rhine only the amount of carbonate of lime was below that of the suspended substances, at the time when it was remarkably swollen and turbid, in March, 1851. But in the water taken in March, 1852, it far exceeds this amount. The amount of carbonate of lime in the water of the Thames is always much larger than that of suspended substance; and it rises to such a degree that the latter is proportionately insignificant. Since the Thames derives its supply of water chiefly from the chalk series, the suspended substances, consisting chiefly of carbonate of lime, are for the most part dissolved.*

As the rivers in the temperate zones are rarely swollen and turbid for any long time together, the mean annual amount of lime in their water is certainly always greater than that of the suspended substances. In the rivers of the tropical zones, which are flooded and turbid during the whole rainy season, the amount of suspended substances, in proportion to carbonate of lime, would be much larger. In the water of the Ganges, probably, the proportion during the four months of rain† may be near that in the water of the Rhine in March, 1851; although, since the water is low during the other eight months of the year, the average amount of carbonate of lime may exceed that of suspended substances. In the rivers of the frigid zones, the water will probably contain as little suspended substance during the greater part of the year as the water of European rivers in winter time. Therefore, the amount of carbonate of lime in the water of these rivers will, on the average, much exceed that of the suspended substance.

If the carbonate of lime in the waters of those rivers, which on the average contain much more of this substance than of suspended substance, were deposited at the same place in the sea as the latter, much more limestone than clayslate would be formed. But this cannot be. Independently of the carbonate of lime derived from rocks on the sea coasts, it is chiefly by rivers that this carbonate is carried into the sea and supplied to the ocean. By means of currents this carbonate of lime is distributed to the remotest points. But the suspended substances cannot be carried so far. These are deposited in the neighbourhood of the coast, though, perhaps, far in the sea. Wherever there are shell fish and marine plants, which separate carbonate of lime from sea water, limestone deposits are formed. If the shells of these fish are imbedded in mechanical sediments, these become calcareous.

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* The analysis of these suspended substances is very desirable.

† English edition, i, 75.

In many sandstones belonging to different geological series, the shells or other calcareous parts of buried animals are entirely destroyed or removed. Their former existence is indicated only by the hollow spaces or impressions. The geological series in which this is the case may be either the oldest or the most recent. Dr. Römer states that in the fossils of the Rhenish grauwacke there are traces of carbonate of lime. In limestone, or in calcareous strata, the shells are generally well preserved, or converted into calc-spar, fibrous limestone, or granular limestone. Even in the sea such a change goes on.* Marly limestone occurs in the muschelkalk series, however, in which the calcareous shells are entirely destroyed, and hollow spaces remain.

Most strata are known only at or near the surfaces, and to these parts only do the observations of the destruction of shells refer. At greater depths the shells in the same strata appear to be preserved, and the rock also to contain some proportion of carbonate of lime. In the strata of the Devonian grauwacke and arenaceous slates, this connection may also be traced as in the miocene sandstone strata of Grafenberg, near Dusseldorf.†

Since the animal remains present the same character in the oldest as well as in the tertiary series, it follows that even the age of the latter is sufficient for the destruction of the organic substances, so as to admit of the carbonate of lime being removed by water. The reason why this takes place in sandstone to a greater extent than in limestone, is that sandstone is more readily permeable by water than limestone, and that the water coming in contact with calcareous fossils in limestone is already charged with carbonate of lime.

Dolomite generally contains only external and internal impressions of fossil remains, and only in some instances rather more well preserved portions; but even the former appear to have disappeared. According to v. Strombeck‡ calcareous shells are not met with in the Jurassic dolomite at Muggendorf, but only their impressions, filled with a white earth, apparently consisting chiefly of silica with a little carbonate of lime. Rings of silica were recognizable in some instances. In the belemnites, only the outer layers consisted of white friable silica, often with many concentric rings, frequently with many concentric rings, the interior consisting of crystalline calc-spar. At the Kahlenberg, near Echte, v. Strombeck* found the dolomite near the limestone full of almost cylindrical cavities, with small rhombohedrons originating from *nerinæea*, which have disappeared together with the nuclei. The fossils are less distinct the more distant the dolomite in which they are found, is from the limestone.

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* English edition, ii, 99.

† I am indebted for these remarks, as to the destruction and preservation of calcareous shells, to Hr. v. Dechen.

‡ Jahrb. für Min., 1833, p. 95.

The succession of mechanical deposits, and of those produced by organic action of marine animals, from the transition series of rocks to those of the tertiary series, shows that a general formation of each of them has commenced with the deposition of conglomerates and sandstone. It is a matter of course that the deposits, consisting of coarser particles, should have been formed first. Thus in the Silurian and Devonian series conglomerates form the underlying beds, and are not repeated in the upper parts of the series. It is only in the Silurian series in North America that there is an exception to this rule, the conglomerates in this instance being among the uppermost strata.

The fall of existing rivers has progressively diminished in consequence of the excavation of their beds at the upper portions of their course, and the silting up of their mouths. When such deposits or delta formations do not occur, the reduction of the fall of the rivers is merely due to the other cause alone.

In mountainous districts the rivers, and especially the brooks, have generally a considerably greater fall than the main streams into which they fall. They, therefore, carry detritus into the latter, especially during times of rain ; and this material, consisting of gravel and shingle and suspended substance, is accumulated at the mouths of the rivers, forming small deltas. If the main stream is unable, even when the water is high, to remove this detritus, the tributary streams are compelled to force another outlet.

When streams pass, like those of the Alps, through lakes, there is a great difference between their course from their sources to these lakes and that from these lakes to the sea. The level of the lakes remain the same, with the exception of slight variations in different seasons.† Consequently, the fall of these rivers can be diminished only by the excavation of their beds near their sources. If the lakes should be filled up by the detritus of the rivers, the bed of the river would be raised within the area of the lakes, and consequently the level of water in these rivers would also be raised. Within this portion of their course the fall would be inappreciable, but it would be increased below the site of the former lake. So long, however, as the lakes are not filled up, although they may be contracted by the formation of deltas, the fall of the rivers flowing from them into the sea cannot be essentially altered.

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* Jahrb. für Min., p. 81.

† English edition, i, 87.

Rivers like the Rhine, the Rhone, and most of the great Alpine streams, which rise in glaciers, do not excavate their beds to any great extent, while their fall is inconsiderable. Here, there are two distinct cases to be considered. During the warm season, the large masses of detritus, brought down by avalanches from the heights covered with perpetual snow, upon the glaciers, and detached from the declivities of the mountains between which they are situated, melt the surrounding glacier ice, and sink deep into it. By the advance of the glaciers, they are gradually brought to the deep precipice at the lower end, and then fall down. In the course of time, this detritus accumulates so that it forms considerable hills, called moraines. The detritus falling into the bed of the glacier streams hinders their course, more especially when the fall is inconsiderable below the glacier. It is only during warm weather when much ice is melted and these rivers are thereby much swollen, that this detritus can be carried away. When the detritus thrown down from the glaciers is more than can be carried away by the rivers, their beds are not deepened, but, on the contrary, raised; and the fall below this point is increased.

The masses of rock detached from the summit of the Alps, and falling into the fissures and gorges, penetrate to the bottom of the glaciers, occasioning the deepening of the beds of glacier streams within the glaciers to a considerable extent. By the advance of the glaciers, they are covered, and, being exposed to the pressure of enormous masses of ice, the beds are deepened more than by the shingle that is carried forward by the water of rivers. This detritus advances with the glaciers, and at the end of them is accumulated, at the same time contributing in this way, to hinder the progress of the glacier streams beyond the glaciers. Therefore, while the beds of the glaciers are constantly deepened, the land, beyond the glaciers, is progressively raised. Either way, the fall of the glacier streams is diminished without their current being decreased, because the water originating from the melting of the ice, in the glaciers, increases the pressure.

When the deepening of a valley by a river has advanced more rapidly than the deepening of the valleys through which its tributaries flow, waterfalls were formed in the latter. Since waterfalls recede, as is so clearly shown by the falls of Niagara, and since the rivers above the falls deepen their beds continually, and carry forward, the loose detritus which accumulates at the foot of the fall, the height of the fall is gradually decreased, until, ultimately, it disappears, the sudden descent being spread over a long extent of the river.

The fall of detritus at waterfalls is very evident in the case of the Staubbach, in the Lauterbrunn valley, in Switzerland. As I was making thermometric observations at the foot of this fall where the water is discharged over a precipice of 500 feet, a stone as big as a hen's egg, fell deep into the ground covered with similar fragments of stone.* The considerable heap of stones at the foot of the fall, shows that this must be a frequent occurrence.

The waterfalls of large rivers, such as that of the Rhine, at Schaffhausen; at the castle of Laufen; the Glomen near Sarp, in Norway; the Götha-Elv, near Göthenburg; the Tigris, Ganges, Nile, Senegal, the American rivers, &c., show that these rivers have not yet completed their valley formation, and that a time will come, though probably very remote, when all these waterfalls will disappear. Many cataracts of the American rivers are said to have been formerly much higher, and Humboldt † has ascribed this chiefly to the accumulation of detritus at the foot of the falls.

The famous falls of Niagara, present the rare phenomenon of being situated in a country that is not mountainous, but at the spot where the river falls from the level of the Erie lake to that of the Ontario.‡

Mr. Bakewell, sen., who visited the Niagara in 1829, made the first attempt to calculate, from the observations of one who had lived forty years at the falls, and who had been the first settler there, that the cataract had, during that period, gone back about a yard annually. But, after the most careful inquiries which Lyell§ was able to make, during his visit to the spot in 1841-2, he came to the conclusion that the average of one foot a-year would be a much more probable conjecture.

If the deepening of a valley by a river ceased, the tributary streams would still continue to deepen their beds as long as there were waterfalls in their course. In districts were the tributary streams come from great heights, and have proportionately short courses, waterfalls are most frequent, as, for instance, in the Alps. Since, according to Elie de Beaumont's* observations, the most fractured strata of the Alps belong to very recent geological series, it follows that the dislocation of these strata has taken place since their deposition. It is the more recent tertiary strata of the shell-molasse that are tilted, consequently the elevation of the Alps was subsequent to the deposition of the detritus. Elie de Beaumont distinguishes, in Europe, thirteen different mountain systems as regards age and direction, and, among these, that of the Western Alps, and the main ridge of the Alps, from Wallis to Austria, are next to the Tänarus system, the most recent.

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* Poggend. Annal, xxxvii, 260.

† Reisen, German edition, iv, 52 and 60.

‡ Fairholme, London and Edinb. Phil. Mag., xxv. 11.

§ Principles of Geology, 7th Ed., p. 204.

After these elevations, if they took place rapidly, according to Beaumont's view, and during the gradual elevations, the watercourses must have been changed. In the Alps this change took place much later than in the older formations, consequently the erosion in the former case is not so far advanced as in the latter. It must, however, be remembered that in the Alps, which are the highest mountains in Europe, the fall of streams is the greatest, and consequently that the erosion within equal periods would be much more rapid than in the districts where the mountains have proportionately very little elevation. In addition to this, the snow-capped summits of the Alps, and the glaciers descending from them, yield much more water than mountains that do not possess such summits within the snow region; but the greater the quantity of water in the rivers and streams, the more their beds would be deepened. The steep declivities of the mountains and the frequently precipitous character of the rocks above the valleys, are, as may be readily understood the chief causes of waterfalls.

When a river, like the Aar in the Hasli valley, had, within a distance of some twenty English miles, a fall of 3,800 feet, it would continue to deepen its bed as long as it flowed. This copious stream has, besides several small falls, one of the largest falls near Handeck, in Switzerland. According to my recollection, its height is about 400 feet, and just before reaching the Grimsel there is another fall. Above these falls it would, in consequence of their retrogression, deepen its bed much more than below them, where it would be raised by the detritus carried into it. So long as this erosion continues, and these waterfalls exist, the streams that fall into the Aar will continue to deepen their beds, and their waterfalls will remain. These waterfalls are, therefore more likely to remain than those of streams falling into a river that has already ceased to deepen its bed.

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* Poggend. Annal., xxv, 33, et seq.

The large masses of detritus carried down by a stream so rapid, and containing such a body of water as the Aar, are discharged into the lake of Brienz, which is only six miles long and one mile wide. This proportionately small lake, into which the Lüschine falls with considerable incline, may, therefore, be filled up much sooner than any other of the Swiss lakes, at least sooner than the much larger lakes, which receive the Rhine and Rhone. Since the Aar, after flowing from the lake of Brienz for a distance of two miles, and falling into the Thuner lake, can convey into the latter only the suspended substance; and since, among the numerous small streams that fall into it, the Kanderbach which has only been recently led unto it, is the only one of any magnitude that carries in detritus, it is evident that the Thuner lake, which is from eight to ten miles long and two miles broad, will not be filled up with detritus until long after the lake of Brienz. The former lake is much deeper than the latter, probably in consequence of these circumstances.

There are also many waterfalls in the Pyrenees; ten or twelve cataracts descend from a rock, 1,400 feet high, on the Marboré, the highest of which is said to be 1,250 feet. In these mountains also the connection between the relatively recent date of the elevation and the occurrence of waterfalls is evident, for according to Elie de Beaumont, the Pyrenees have assumed their present position between the periods of the deposition of the chalk strata, which, according to Dufrenoy's observations, extend to the summit of these mountains, and prior to the deposition of the tertiary strata.

In the Scandinavian peninsula there are some fine waterfalls, mostly of small height, and some as high as 100 feet; between Bergen and Stavangre, however, there are two waterfalls, one scanty but 1,600 feet high, and consequently the highest one known; the other discharging as much water as the Seine, and still 945 feet high.* Dr. Daubeny observed, that in Norway the mountains often plunge so abruptly into the Atlantic, as to leave scarcely any interval of coast between them and the sea.† Here, therefore, the rivers fall into the sea at a very great incline, and form cascades. Hence it follows that these rivers will long continue to deepen their beds, and that the flow of streams in

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* Nouvelles Annales de Voyage, xvii, 148.

† Hints for inquiry, suggested by a recent tour in Scandinavia, p. 1.

Norway can have commenced only within a comparatively short space of time. The elevation of this country above the ocean is, therefore, a recent occurrence; and this inference is consistent with the fact that a great part of the peninsula is still being raised. If this elevation should progress in the same degree as the erosion of the valleys, the present conditions of considerable fall in the rivers would be maintained until the elevation of the land had reached its maximum.

Rivers which, like those of Norway, fall into the sea at a great incline, carry into it not only suspended substance, but also coarse gravel, and, consequently, diluvial deposits would be produced on the coasts. If these deposits rise above the water level, the rivers will cut their beds in deposits that have been previously formed by them.

It appears, therefore, that in Norway, as in the Pyrenees and in the Alps, the existence of waterfalls is connected with the relatively recent date of the elevation of the mountains.

Sedgwick has shown that the slate rocks in the lake district of Westmoreland assumed their present position before or during the deposition of the old red sandstone. Elie de Beaumont* adds that the inclination of these strata as well as that of the Rhenish slate strata, has been produced by the same cause, which is also the earliest of which there are any distinct traces yet recognized.

The flow of water in clay strata and grauwacke rocks is, therefore, one of the oldest geological phenomena known. Comparing with this, the flow of water in the Alps, it appears that this did not commence until after the whole series of the sedimentary rocks form old red sandstone to the most recent tertiary deposits had been formed.

During this period, the length of which cannot be estimated, the Rhine continued to cut its bed, and it is not to be doubted that this erosion has long been at an end. From Königswinter above Bonn, where the Rhine leaves the clay slate, to where it falls into the North Sea, this river has cut its bed in its own deposits, but it is not likely that it will deepen its bed here any further, since it continually carries down gravel from above. Such a deepening of the bed of a river in its own deposits is a certain indication that the river had formerly cut a deeper bed, or that its present course is through the bottom of a former sea or lake, which was filled up with detritus by the river.

Since after the elevation of the Rhenish slate rocks their declivities formed the coasts of the North Sea, the Rhine must have fallen into the sea or into a bay of the sea near Königswinter. This place is 150 feet above the level of the North Sea, and, consequently, if since the time of their elevation there has not been any essential alteration of the sea level, the level of the sea at that time near Königswinter must have been 150 feet below the present level of the Rhine. Therefore, all the detritus that the Rhine then carried down would be deposited directly in the bay of the sea there which extended from that point for 160 miles to the place where the present coast of the North Sea is situated, and was gradually filled up with detritus to the present height of the Rhine valley and Netherlands. The whole of this district is, therefore a delta of the Rhine, in which the stream has cut its bed. In accordance with the above assumption the thickness of the detrital deposits near Königswinter must be at least 150 feet. The actual thickness of these deposits is not yet known.

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* Loc. cit. p. 12.

Assuming that the bed of the Rhine above Königswinter, at the time when the sea extended to that point, had the same level as at the present time, the stream issuing from the clay slate rocks must have formed a waterfall of 150 feet, and at that time the Rhine would have fallen into the sea in the same manner as the rivers of Norway do at the present time. But if the clay slate, according to Beaumont's opinion, was suddenly raised to its present level, the Rhine at that time would have flowed far above its present level, and in this case its waterfall would have been much more than 150 feet high. However, the mass of water was then much less than at the present time when it flows gradually into the sea. At that time only the Rhenish slate rocks projected as an island above the ocean, so that the river received only the water flowing over these rocks, consequently, the brooks and rivers which now fall into the Rhine between Bingen and Königswinter. These streams are inconsiderable, with the exception of the Moselle, Lahn, and Wied. The former two discharged into the Rhine, at that time only the water that flowed from the slate rocks, not that which is at the present time derived from more recent strata. The Rhine of that time was, probably, a river somewhat like what the Moselle now is.

If the Rhenish slate rocks were gradually elevated, three cases may be supposed to have obtained. If during equal periods the elevation was as great as the erosion, the bed of the Rhine would always have maintained the same level. If the elevation exceeded the erosion, the levels of the river bed would be raised; if the elevation was less than the erosion it would have been depressed.

In the neighbourhood of Boppard, on the Rhine, v. Dechen * found Rhine shingle at a height of 629 feet above the level of the river, and at another place 790 feet above its level, quartz pebbles. Therefore the bed of the river must have been at least 629 feet above its present level at the time when these pebbles were deposited. Of the above-mentioned three possible cases therefore, only the second, namely, the gradual elevation exceeding the erosion, can be supposed to have obtained. Consequently the bed of the river was raised continuously, although in a less degree than the parts of the rocks that were not eroded, and as a result of this the height of the declivities of the valley was progressively increased during the period of elevation.

If the bed of the Rhine had attained the height of 629 feet above the present level the conditions would have been essentially different. If the elevation of the mountains still progressed the third case would obtain, the erosion exceeding the elevation. The stream would then continue to deepen its bed to the present level.

Since not only the present gravel of the Rhine contains besides clay-slate and grauwacke, fragments of more recent rocks, such as variegated sandstone, but even at considerable heights above the present bed of the Rhine the same circumstance is observed, it follows that after the elevation of these more recent strata the bed of the Rhine was far above its present level with few exceptions.

The foregoing observations show that existing rivers carry only finely suspended substances into the sea.

It cannot be supposed that they will ever again transport large masses of coarse materials, unless the relations of height in their several regions becomes essentially different from what it is. But if at subsequent periods elevations should take place in these districts as in Alpine mountains, by which the fall of the rivers is restored to its former degree, then coarse gravel would be again carried down to the sea, and this would form the commencement of a series of strata.

It may be supposed that the commencement of a new series of strata, beginning with the deposition of coarse materials, might be a consequence of the sudden destruction of the rocky sea-coasts. The fragments of adjoining older rocks in the conglomerates of the carboniferous series are indicative of such an origin. But we must not forget that there are no grounds for supposing that the action of the sea upon coasts was greater during former ages than it is at the

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* Verhandlungen des naturhistorischen Vereins der Rheinlande, &c. Jahrgang, vii, pp. 383 and 384.

present time. The transport of coarse gravel by rivers during long periods while the fall of the rivers was not materially reduced—the accumulation of this gravel at the mouths of these rivers over large extents of surface appear to me the phenomena to which the commencement of a new series of strata is much more consistently to be ascribed than to the partial action of the sea upon coasts; although the latter action has certainly given rise to the formation of individual beds of conglomerate included among deposits of more finely divided materials.

Limestone strata have, in all geological series, generally been deposited subsequently to conglomerates and sandstone. Sometimes, however, the Devonian and also the oolitic series commence with limestone; at these places, therefore, there was a deficiency of material for the formation of mechanical deposits, and the marine animals that separate carbonate of lime could begin their work at once. Moreover, it must be remarked, that the classification of the large series of sedimentary strata into separate groups is merely artificial, although based upon resemblance or dissimilarity of the organic remains; that this classification has undergone numerous changes; and that, in many instances, geognosts are not unanimous in their opinion as to whether certain strata are to be included in one or other series. But even independently of this, the transition of many limestone strata into mechanical deposits in the same series of strata—as, for instance, in the carboniferous series, shows that simultaneous deposits were not always identical. Near to the mouths of rivers in the old continents conglomerates were formed; at greater distances sandstones were formed, and at still greater distances—to which only suspended substances could be carried—clay and slate were formed; while in the clear water at the greatest distance from the shore limestone was deposited. If, during the progress of such simultaneous but dissimilar deposits, alterations took place, the coarser parts at the bottom of the sea and the substances suspended in the sea-water being removed further or driven back, or the clear water coming nearer to, or receding further from, the coast, the result would be the formation of an alternation of dissimilar deposits at the same spot.

Since in the Jurassic series at many places limestone preponderates, at others clay and marl strata; this arises undoubtedly from the circumstance that the latter were deposited near the coasts of the former ocean, while the former were deposited only at a distance from them, where the water was clear. The suspended substance that furnished the material for bituminous strata must have been saturated with organic substance in the same manner as that in the water of the Thames and the Vistula*, which, according to my analyses, contain 23 and 21 per cent. of organic substance.

The remarks previously made† in reference to limestone deposits are confirmed by the conditions of situation of limestone rocks, and by their alternation with mechanical deposits. Since vegetable remains seldom occur in white limestone, only a slight share in their production can be ascribed to plants. The contrary appears to have been the case with the dark-coloured or black limestone; for the carbon with which this limestone is often saturated throughout, probably originates from vegetable remains. The plants that contributed to the formation of these strata were probably analogous to the varieties of *chara*, in which the amount of carbonate of lime rises as high as 66·7 per cent. of their weight.‡

The marine animals that separate calcareous substances from sea-water do not appear first at the later periods in which limestone rocks seemed to have been formed; for even before the deposition of carbonate of lime, there seem to have been fish in the sea, their remains being found in the sandstone strata. Thus it is not probable that those imperfect animals, such as corals, come into existence later than fish which stand higher in the scale of organization. This pre-existence of animals that separate limestone, becomes a certainty when it is remembered that, in the southern parts of Devonshire, there are beds of limestone rich in corals, even among the oldest members of the Silurian series; and that, in the northern Devonian zones of Russia, limestone follows directly after Silurian strata. So long as the formation of mechanical deposits was predominant, the organic action of the marine animals that separate limestone, or at least that of the corals, could not be exercised.§ That, however, the agency of these animals commenced while formation of mechanical deposits was still going on, is evident from the frequent alternation of limestone with clay-slate, and its occurrence among the members of the old red sandstone series. When the formation of mechanical deposits predominated, limestone deposits were formed only in patches and irregularly; or these deposits were mixed with the former, and only at a subsequent period the disseminated particles of carbonate of lime were gathered together to limestone concretions by the action of water permeating these strata.

Such concretions, as well as the carbonate of lime, recognizable only by effervescence with acids in certain sandstones and slates which, in different series, underlie limestone, certainly owe their calcareous admixtures chiefly to the latter; for the fissures and cavities in these strata show that considerable quantities of carbonate of lime have been removed by means of water. This action may not have taken place until after these rocks were elevated above the level of the sea; for in this case the water, permeating the rocks, could have become charged with carbonate of lime and deposited it in the underlying strata.

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* English edition, i, 72. † Ibid., i, 171. ‡ Ibid., i, 195. § Ibid., i, 172.

If limestone had been formed from calcareous mud suspended in the sea, as some geognosts suppose, pure or nearly pure limestone would never have been formed, unless these rivers flowed only through limestone rocks from their sources to their mouths. But then these rivers would have produced only limestone and never sandstone or clay deposits. There are, however, no grounds for supposing that, during the sedimentary period, the rivers carried other substances into the sea than at the present day. If, as in the case of the Danube at Vienna*, they had carried into the sea carbonate of lime in a state of suspension, they would have given rise only to the production of calcareous slate, but could never have produced pure limestone. The general sharp distinction between limestone deposits and the mechanical deposits in sedimentary rocks shows decisively that these different deposits were formed under entirely different conditions.

The rivers Dee and Don† show how little carbonate of lime is present in the water of rivers flowing from granite; and this fact may be easily accounted for, since orthoclase contains but mere traces of calcareous silicate, though rather more is present in oligoclase. In the waters of the Möll and of the Oetz‡, which rise in crystalline slates, there is also but very little carbonate of lime. By far the largest quantity of this substance is taken by rivers flowing from limestone rocks; for the augitic and amphibolic rocks, which contained silicate of lime in large amount, are too unfrequent to have furnished much carbonate of lime by their decomposition.

It is only in the slates destitute of organic remains that we are acquainted with beds of granular limestone that could have furnished carbonate of lime to the water of rivers prior to the formation of the transition rocks. Whether they were as widely distributed as the present limestone rocks we do not know. But extensive masses of rock must have existed, by the disintegration of which such large quantities of suspended substances could be carried into the sea, as were requisite for the formation of the transition rocks. The rocks that furnished the material, might have been granite or gneiss, for these rocks vary in their composition so much, that the different members of the transition series from sandstone and quartzose grauwacke, to the clay-slate destitute of quartz, might have been produced from them. But they could not have furnished much carbonate of lime to the water of rivers. Nevertheless, there was evidently an abundance of carbonate of lime for the formation of enormous beds of limestone subsequent to the mechanical deposition of the first members of the Silurian series. Although it is not possible to estimate the relative proportion between mechanical deposits and calcareous deposits in the transition rocks; still it is clear that the small amount of carbonate of lime that would have been furnished by granite or gneiss, cannot possibly have been sufficient for the formation of those calcareous deposits. Therefore, it must be inferred either that the sea contained carbonate of lime as an original constituent in its water, or that other rocks, containing this substance, or silicate of lime, from which it might be derived by decomposition, were washed down simultaneously with the materials originating from the disintegration of granite and gneiss. Probably the carbonate of lime in the transition rocks, originated from both these sources. The existence of beds of granular limestone, intermingled with strata destitute of organic remains, shows that sea-water contained carbonate of lime prior to the formation of the transition rocks, for those beds were also of sedimentary origin.

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* English edition, i, 76.

† Ibid., p. 77.

‡ Ibid., p. 77.

It is, at least, certain that all calcareous rocks existing prior to the formation of the transition rocks, underwent the same change as the calcareous rocks of the present time. During their disintegration, the lime was carried into the sea in the state either of carbonate or silicate.

These remarks are also applicable to the limestone rocks of other geological series subsequent to the transition series. Since there is a progressive increase in the proportion of limestone deposits in relation to mechanical deposits, and especially in relation to the deposits of clay-slate, originating from substances suspended in the water of rivers, it follows that the amount of carbonate of lime in the water of rivers, must have increased in the same degree. This is, however, perfectly consistent with the observed alternation of strata constituting the crust of the earth. If the rocks at the surface, prior to the formation of the transition rocks were all poor in lime, the rivers would carry down to the sea less lime, but at least as much suspended substance as at the present time. Consequently, the material for the formation of mechanical deposits would be proportionately more abundant than that for the formation of limestone. But since there was a long period during which only mechanical deposits were formed, as is shown by the lowest members of the Silurian series, the amount of carbonate of lime in sea-water would increase. Afterwards, when the agency of vital organisms commenced, the limestone strata of this series were formed. If these strata were elevated above the surface of the ocean, and a new course of rivers resulted, the water of these rivers would take up more carbonate of lime than was formerly the case, and the proportion of suspended substances would be reduced. But the greater the diminution of suspended substances, and consequently of the formation of mechanical deposits, and the greater the increase of carbonate of lime, the greater would be the opportunity for the exercise of vital agency in forming considerable deposits of limestone. If these deposits were subsequently elevated above the ocean, increasing portions of the dry land would consist of limestone rocks; and the amount of insoluble suspended substances would be progressively diminished, until, finally, the existing relation between these materials in the water of rivers would be established, and carbonate of lime would preponderate over the suspended substances. The unusual preponderating amount of carbonate of lime in the water of the Thames, flowing chiefly through calcareous strata, and the minimum proportion of suspended substances in its water, shows distinctly the extent to which these latter materials may be diminished, when in the district through which rivers and their tributaries flow, calcareous rocks predominate over schistose, granitic, or gneiss rocks.

Alteration of Sedimentary Rocks.—Those rocks containing silicates may be converted into crystalline siliceous rocks. This fact will be illustrated in treating of the metamorphic rocks in a subsequent chapter. Sedimentary limestone is also capable of being converted into crystalline limestone and dolomite.

Decomposition of Sedimentary Rocks.—The rocks containing silicates are liable to the same kind of decomposition as the crystalline and metamorphic rocks containing silicates, and these changes will be treated of in a subsequent chapter. The decomposition of sandstone rocks will also be treated of subsequently.

Since the publication of the first volume of this work a valuable memoir has been published by P. Harting,* the chief results of which are as follows: In making borings to a depth of 232 feet under Amsterdam, nineteen different strata were penetrated. Among these there are eleven beds of clay, the total thickness of which is 153 feet, alternating with eight beds of sandstone, 79 feet in thickness. At the depth of from 200 to 900 and 1800 feet, beds of sand only were encountered. Portions of four of the clay beds were submitted to chemical analysis. After being thoroughly washed with water they were treated with hydrochloric acid, and afterwards completely decomposed. The bases and acids obtained from these several solutions are shown below, the carbonic and sulphuric acids being divided among the corresponding bases.

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* De Bodem onder Amsterdam. 1852.

	I	I A	II	II A
Silica	44·35	64·51	76·14	87·41
Alumina and Peroxide of iron	19·78	28·77	6·75	7·75
Protoxide of iron	1·70	2·47	0·93	1·07
Oxide of manganese	—	—	0·50	0·57
Lime	Spur	—	0·66	0·76
Magnesia	1·12	1·63	1·81	2·08
Potash	0·62	0·90	0·10	0·11
Soda	1·18	1·72	0·22	0·25
Carbonate of lime	12·20	—	3·10	—
„ magnesia	2·12	—	—	—
Sulphate of lime	0·46	—	—	—
Iron pyrites	3·33	—	2·50	—
Organic substance	12·84	—	6·43	—
	99·70	100·00	99·14	100·00
Water	20·42 per cent.		2·85 per cent.	

	III	III A	IV	IV A
Silica	48·79	83·17	43·93	56·71
Alumina and Peroxide of iron	6·53	11·13	19·06	24·61
Protoxide of iron	1·13	1·93	6·60	8·52
Oxide of manganese	0·90	1·54	0·63	0·81
Lime	0·38	0·65	2·36	3·05
Magnesia	0·77	1·31	4·02	5·19
Potash	0·16	0·27	0·41	0·53
Soda	—	—	0·45	0·58
Carbonate of lime	9·22	—	12·55	—
„ magnesia	1·34	—	—	—
„ protoxide of iron	1·56	—	—	—
Sulphate of lime	1·69	—	0·80	—
Iron pyrites	4·32	—	—	—
Organic substance	19·95	—	7·55	—
	96·74	100·00	98·36	100·00
Water	8·09 per cent.		4·62 per cent.	

I. Peaty clay from a depth of 31 feet and 13½ feet thick, containing remains of land plants. It contains but few granules of quartz, but numerous translucent granules and laminæ of mica, with sharp edges, and crystals of iron pyrites.

II. Yellowish-grey clay-marl from a depth of 53 feet, and 11 feet thick.

III. Diatomaceous clay from a depth of 138 feet, forming a bed 8 feet thick.

It differs from the preceding beds in containing the siliceous shells of innumerable organisms, amounting to one-third or one-half its entire mass. Besides these diatomaceous shells, this clay contains remains of plants. In none of the other beds is there such a large number of organic remains as in this one. Many of the shells are filled with crystals of iron pyrites.

Harting gives hydrated peroxide of iron and basic sulphate of alumina among the constituents; but as I have represented the sulphuric acid as combined with lime, the amount of carbonate of lime would, according to his view, be somewhat increased, and that of carbonate of lime and alumina somewhat reduced.

IV. Compact clay-marl from a depth of 166 feet, forming a bed 11 feet in thickness. This does not contain recognizable organic remains.

The numbers in the columns I A, II A, III A, and IV A, give the composition of these specimens, after deducting carbonates and sulphates, iron-pyrites, and the organic substances. The small amount of chlorides, sulphates, &c., extracted by water and the phosphoric acid, amounting to 0·12 per cent., were not taken into account, and represent, in part, the deficiency in the analytical results.

The composition of these beds has some resemblance to that of the marl, containing carbonate of lime.* The numbers in the columns marked A present a still greater resemblance to the composition of clay, slate, and of grauwacke; I A corresponds almost entirely with the suspended substances in the water of the Rhine;† and II A and III A approximate closely to the deposits formed by that river in the lake of Constance after deducting the carbonates.‡

The diatomaceous clay, represented by column III, can be only, in part, a deposit from river-water, for the original amount of silica has been increased by the shells of the diatomacæ. Deducting one-third as silica, the composition of the residue will be something between those given in columns I A and IV A, corresponding to that of clay-slate containing little quartz, and it may, therefore, have originated from suspended substances, such as those present in the water of the Rhine at the present day. Such a deposit formed by rivers, might, therefore, after the introduction of silica as siliceous shells, and its hardening by a cementing substance, give rise to a quartzose clay-slate, or, rather, grauwacke.

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* English edition, i, 137. † Ibid., i, 123. ‡ Ibid., 123, (iv.)

Since the amount of silicate of magnesia in the beds analysed is always much greater than that of silicate of lime, while the suspended substances in Rhine water do not present this relation, it may be inferred that the silicate of lime was partially decomposed. This decomposition in a sediment, which, like these clay-beds, contains so much organic substance, may have been owing to the evolution of carbonic acid during its decomposition, or to the action of chloride of magnesium in sea-water, the silicate of lime being thus converted into silicate of magnesia and chloride of calcium. Since in the substances represented by the columns I, II, and IV, the amount of soda is greater than that of potash, while in the suspended substances of river-water the contrary relation is observed, it may be that in these clay-beds a portion of the silicate of potash has been decomposed by the chloride of sodium in sea-water, silicate of soda and chloride of calcium being produced.* .

The presence of protoxide of iron and of iron-pyrites in these clay-beds, arises from the considerable amount of organic substances exercising a reducing action. If these beds were ever to become slate, they would be highly bituminous.

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* English edition, i, 12.

CHAPTER XLVII.

CRYSTALLINE ROCKS.

THE crystalline rocks are partly unstratified—granite, syenite, basalt, etc.—partly stratified—gneiss, mica-schist, etc. The term crystalline rocks merely expresses an observed character, and has no reference to hypothetical views as to the mode in which these rocks were produced; as is the case with the term "plutonic rocks."

From a chemical point of view these rocks may be divided into siliceous rocks and carbonate rocks. The former class comprises such rocks as consist principally of compound silicates, combined so as to form independent minerals—felspar, mica, augite, hornblende, etc. In some of these rocks all the silica is combined with bases; in others silica exists also in a free state as quartz, or rock crystal. The latter are distinguished by the name of quartzose crystalline rocks. There are also crystalline rocks—quartzite—consisting essentially of silica.

The carbonate rocks consist chiefly of the carbonates of earths —crystalline limestone, dolomite, etc. These rocks either do not contain any silicates, or only subordinate proportions.

Besides the minerals which are essential constituents of crystalline rocks, other minerals are met with, which are not essential constituents; but generally these are in very small proportion. These minerals will be referred to in treating of the several crystalline rocks.

The distinction between stratified and non-stratified crystalline rocks does not in any way correspond with their classification according to the minerals which they contain. Thus, gneiss and granite are essentially identical as regards the minerals—felspar, mica, and quartz—of which they consist; but the former is stratified, the latter is not. Again, neither granite nor basalt are stratified; but they consist of entirely different minerals.

Occurrence.— The crystalline rocks are very widely distributed; but they occur much less frequently than sedimentary rocks. They are met with, in part constituting entire mountain ranges;

in part sporadically in the midst of sedimentary formations. The special features which they present will be considered in treating of them individually.

Formation.—The remarks that have already been made in reference to the formation of minerals in general,* apply equally to crystalline rocks, whether these rocks constitute mountain masses or occur in fissures of other rocks. The difficulty, or rather indeed the impossibility of accounting for the formation of crystalline masses by fusion, is most obviously indicated by their occurrence in narrow fissures.

The adherents of the Plutonic theory regard these rocks as having been formed either from melted masses or from sedimentary rocks, by a process of igneous metamorphism. In support of this view it is urged that the silicates, of which these rocks chiefly consist, are not known to be produced in any other way than by fusion. But there is no other evidence that they are produced by fusion, than the analogy between the silicates in crystalline rocks, in lava, and in other volcanic products, and those which may be produced artificially by fusion. Moreover, when it is considered that it is only in old lava and other volcanic products that large and well developed crystallized silicates occur, while the recent lava does not contain any, or at most only very small crystals that are rarely well developed,† it will be evident that the argument based upon this analogy between the minerals in lava and artificial silicates is not of much value.

Rudberg's ‡ experiments have furnished a complete elucidation of the processes which take place in melted masses during gradual cooling and solidification. According to his observations a melted mass consisting of two metals in any proportion, is to be regarded as a mixture of an alloy of those metals in atomic proportions, with the metal that is present in excess. When such a melted mass is gradually cooled, this excess solidifies first and then the alloy, the two remaining mechanically mixed. This fact may be applied to the case of lava, with this difference, that there are a greater number of substances melted together. A homogeneous leucitic lava § may be regarded as a mixture of leucite, and a mass containing the other constituents of the lava. In cooling, the less fusible leucite would be first solidified; then the remaining mass. If this mass were itself a mixture of several substances there would be a sequence in their solidification, according to their fusibility.

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* English edition, i and ii.

† Ibid., ii, 94 and 228.

‡ Ibid., ii, 93.

§ Ibid., ii, 221.

If leucite were separated in this manner it would be owing chiefly to the considerable difference in fusibility between it and the other constituents of lava. Such a prior solidification of leucite might be expected to take place in the crater of a volcano, since there gradual cooling—the condition most favourable for such a result—would obtain it in an eminent degree.

Rudberg observed, also, that in the cooling of a melted metallic mass, the temperature remains stationary for some time, during the solidification both of the metal in excess, and of the alloy, in consequence of the evolution of latent heat. Such a conservation of temperature, arising from this circumstance, would also obtain in the case of lava, and would be greater in proportion to the magnitude of the mass. This would still further favour the production of large crystals of leucite, and their perfect development. Nevertheless, the result of the investigation which I have bestowed upon this subject shows that the evidence of facts* is in favour of the origin of leucite in the wet way rather than by fusion.

Minerals which do not contain water, and which are not decomposed or volatilized by heat, may, indeed, have been produced in some instances by igneous action; but the examination of facts relating to the occurrence of minerals in crystalline rocks proves the impossibility of these minerals having been produced in such a manner.† Moreover, these facts furnish evidence that the minerals treated of in the previous volume have been produced in the wet way. This evidence, also, is direct, and independent of any hypothesis.

Further evidence of the impossibility of the igneous origin of minerals is furnished by those crystalline rocks in which the constituent minerals occur, partly as large crystals, partly as crystalline or amorphous masses. This is especially the case with those crystalline rocks containing quartz.

In granite quartz is the more recent mineral. The crystals of quartz are never found to have interfered with the crystallization of the other minerals. This fact is apparent even in rocks that have a granular structure. Th. Scheerer‡ describes dyke-shaped masses of granite in Norway with orthoclase crystals of a cubic foot, mica crystals of a square foot in dimensions, and the quartz in still more considerable masses—at one place 21 feet thick—extending between them. It is everywhere evident that the felspar was crystallized before the mica and quartz. Pegmatite presents the same relations.

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* English edition, ii, 230. † Ibid., i and ii. ‡ Pogg. Annal., lvi, 489.

According to E. Zschau,* in the dyke-shaped masses of granite at Norit, in Hitteroë (Norway), the greatest abundance of foreign minerals occurs in the felspar zones, and more especially in the zones of pegmatite lying between the felspar and the quartz. The large masses of quartz either do not contain any foreign minerals, or only very slight and barely recognizable traces of them. The finest crystals of phosphate of yttria occur when the granite contains small laminæ of white mica. The large crystals of mica would appear to have hindered the crystalline development of the minerals occurring upon them, since here only flat or long crystals are met with.

The phosphate of yttria and malakon† occur as roundish flattened nodules, between the laminæ of mica, which are pushed apart and bent. When the phosphate of yttria occurs at the side of the mica crystals, so as to project partially, the portion that is imbedded is, as it were, crushed, while the portion that is in contact with the felspar or quartz is crystallized. In this granite the mica is the only mineral that appears to have hindered the crystalline development of the foreign minerals. This fact, together with the comparatively good crystalline development of the mica, shows that in this granite it was one of the minerals first produced. On the contrary, the quartz was produced after the production of the foreign minerals had been for the most part completed. Consequently, the order of succession of the constituent minerals of the Hitteroë granite is: 1. Mica. 2. Foreign minerals and felspar. 3. Quartz. The crystallized phosphate of yttria lying in the felspar appears, at least, to have been produced prior to the felspar.

It is deserving of notice, that the malakon occurring in this granite, blended with phosphate of yttria, contains 3·03 per cent. water. If, therefore, the quartz, which was produced subsequently, were a product of igneous action, the condition of fusion must have continued throughout the whole period of the formation of this granite. In this case, however, the presence of a hydrated mineral could not be accounted for. The production, also, of malakon between the laminæ of mica would be equally unintelligible.

The several crystals or groups and nests of minerals in the above-mentioned granite, form, as it were, a distinct series, so that there could scarcely be any more distinct proof in support of the opinion that the mineral substances were disseminated throughout the entire mass of the rock. Thus Zschau found in a granite dyke.

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* Jahrb. für Mineral. 1855—p. 513.

† A kind of zircon.

eight or ten inches thick, about ten large orthite crystals, at distances of from one to three inches apart, and forming a very regular series, extending almost exactly along the middle of the dyke. The constituents of these crystals must have been brought from distances of several feet, since the granite is fissured in lines extending from the orthite for considerable distances. Polycras, malakon, and phosphate of yttria occur mostly associated with orthite. The constituents of these minerals have been brought together after the production of the orthite; the crystals are sometimes found in the central line occupied by orthite, but more frequently at some distance from this.

The occurrence of orthite, malakon, polycras, phosphate of yttria, and gadolinite, is always accompanied by a characteristic radial and irregular columnar structure of the surrounding granite. The central point of these columnar aggregates is marked by single crystals, or by groups of crystals. This fissured character of the rock is very evident in weathered masses: but it is also distinctly recognizable in the unaltered rock. The titaniferous iron ore is not, like the above-named minerals, surrounded by granite, but it presents a radiated columnar structure, and surrounds the granite.

In the coarse-grained granitic masses of the syenite, near Dresden, orthite and malakon are stated by Zschau to occur in the same manner as at Hitteroë.

In the highly felspathic granite of the gneiss near Arendal much larger orthite crystals occur ; but the fissures extending from them through the granite are much shorter than in the case of the much smaller orthite crystals at Hitteroë. Since, in the granitic gneiss near Arendal, felspar is remarkably predominant, and occurs as very large crystalline masses, it is probable that the traces of the passage of the orthite substances may have been obliterated by the production of the felspar. Mica likewise appears to have prevented the access of the constituents, for the production of the hydrated minerals, of orthite, euxenite, and pyrite. This interruption by the mica of the production of minerals appears so frequently, that it appears as one of the minerals that crystallized first.

The fissuring of a rock can only be supposed to take place while it is in the solid state. Consequently, if the granite were originally a melted mass erupted from the interior of the earth, the present radial and columnar structure could only have originated during or after the solidification of the mass. In this case, however, the production of minerals such as those occurring in the granite of Hitteroë whose constituents, as Zschau has shown so clearly, have been brought from distances of more than a foot, could not have taken place. Such a movement of substances can only be supposed to take place in the wet way. The fissured character of the fresh rock shows that this transfer of substances took place before the weathering of the rock began. Nevertheless there is nothing to contradict the opinion that this process of solution and transfer proceeded simultaneously with the weathering. In the same way the minerals imbedded in titaniferous iron ore—phosphate of yttria, malakon, polycras, and orthite—may have been produced by a similar transfer of their constituents through the passages presented by the radial columnar structure of this mass. The above-mentioned arrangement of orthite crystals in very regular rows indicates the course of the water by which the constituents of this mineral were dissolved and transferred to the places where the crystals occur. Wherever the mica that had been previously produced closed these passages, the deposition of crystals would of course be interrupted.

In syenite and other quartzose crystalline rocks, as well as in granite, the quartz is found to occupy the space left by the other mineral constituents of the rock. The quartz presents impressions of the crystals of those minerals without their edges or angles appearing in any way broken or rounded.*

It appears, therefore, that the constituent minerals of granite and syenite were not produced in such an order of succession as corresponds with their respective fusibility. This, however, must have been the case if these rocks were of igneous origin; and in that case, quartz being the least fusible of these minerals, would have crystallized first; while, in reality, the felspar and other minerals were the first to assume the crystalline state.

Fournet has endeavoured to remove this inconsistency by the hypothesis of superfusion, according to which quartz is supposed to have retained a certain plasticity at a temperature far below its melting point. Laurent and myself obtained some experimental results which were in favour of this hypothesis. It was, however, opposed by Th. Scheerer, Schafhäutl, and Studer, and previously Fuchs and de Boucheron pointed out the improbability of a gradual solidification of granite from a melted mass.†

Daubree‡ found that, by passing the vapour of chloride of silicium over bases at red heat, chlorides were produced together with silica sometimes in a free state, sometimes combined with the bases. He holds the opinion, that the association of quartz with silicates in the granitic rocks, may be accounted for by this fact, particularly since he found that the crystallized silica was produced, not only simultaneously, but even after silicates that are more fusible than it, and at a temperature not above a red heat.

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* Delesse—Ext. des Mém. de la Soc. d'Emulation du Doubs.

† German edition, ii, 1292, et seq.

‡ Comptes rendus, xxxix, 153.

However interesting these facts may be in themselves, there is little to be expected by the geologist from Daubree's investigation relating to the plutonic origin of silicates and quartz. Even admitting that vapour of chloride of silicium may have been produced in the interior of the earth, it is easy to show that it could not have given rise to the production of granitic rocks. Thus, for example :—Supposing the bases of felspar and mica in this rock to be exposed to the action of chloride of silicium vapour, this gas must be furnished in quantity sufficient to yield both the silica of the silicates, and that in a free state. Hence, calculating from the composition of granite, the following results are obtained as representing the process that would take place in the production of granite in this way :—

	I	II	III	IV	
Silica	76·02	—	—	76·02	A
Alumina	12·71	61·68	74·39	12·71	
Peroxide of iron	1·25	6·07	7·32	1·25	
Protoxide of manganese	0·31	1·50	1·81	0·31	
Lime	1·20	5·82	7·02	1·20	
Magnesia	0·14	0·68	0·82	0·14	
Potash	4·90	23·78	28·68	4·90	
Soda	2·44	11·84	14·28	2·44	
Chloride of silicium	—	—	211·52	—	
Chloride of aluminum	—	—	—	160·66	B
Chloride of iron	—	—	—	10·70	
Chloride of manganese	—	—	—	2·66	
Chloride of calcium	—	—	—	11·50	
Chloride of magnesium	—	—	—	1·61	
Chloride of potassium	—	—	—	37·63	
Chloride of sodium	—	—	—	22·27	
	98·97	111·37	345·84	346·00	

I. Granite from the lesser Sturmhaube.

II. Bases requisite for the production of silica amounting to 76·02 per cent. of the granite, by the decomposition of chloride of silicium. In calculating these quantities, the bases are assumed to be in the same proportion as in the granite.

III. Composition which the rock must orginally have had in order to yield granite (I) by the action of chloride of silicium.

IV. Composition of the rock after the reaction between the bases and chloride of silicium. A represents the constituents of the granite, and B the chlorides produced.

Hence it follows that:—

1. The original mass consisting of bases would amount to 1·357 ($=\frac{22·96 + 111·37}{98·97}$) as much as the granite (I) produced.

2. By the penetration of chloride of silicium into the original mass it would be increased to 345·84, or 3·494 times as much as the granite. Supposing, therefore, that chloride of silicium vapour to have permeated such a mass so thoroughly, that a complete mutual decomposition took place, and supposing that mass to be shut in between mountains so that there was an outlet only upwards, it is evident that a considerable elevation of the mass would have taken place.

3. Among the chlorides that would be produced by such re-action, perchloride of iron is the only one volatilizable at a red heat, and consequently the only one that would be removed by sublimation meanwhile. The other chlorides would remain in the rock, and, when it became cold, might be removed by meteoric water penetrating the rock. It is true that, in the water of springs rising from granite, chlorides are present in minute proportion, but it is certain that neither these chlorides, nor the still greater amount present in the water of the Carlsbad springs, originate in the manner assumed by Daubree's hypothesis.

4. Owing to the removal of the chlorides produced in this way, the granite would be very porous; for, since the mass of the chlorides would amount to 2·5 ($=\frac{246·76}{98·97}$) times as much as that of the granite, the intersticial spaces would amount to 2·5 times the volume of the granite, independently of the difference in density between the chlorides and granite. However, granite of such structure has never been met with.

If it is assumed that the bases were originally in the state of silicates, and that only so much chloride of silicium penetrated as would be requisite for the production of free silica, or the quartz of granite, then the amounts both of chloride of silicium and of bases would be proportionately less than in the case already considered. But still the granite thus produced would, for the same reason, be porous, although in a lesser degree.

No hypothesis as to the origin of granite which involves the production of a porous rock, can be received as well founded. It would, therefore, be superfluous to demonstrate this by a second calculation. Daubree's hypothesis leads to results which are altogether inconsistent with fact; and, consequently, it affords no support to the opinion that granite and other crystalline quartzose rocks, have originated by igneous action.

Trachytic lava occurs at Ischia, Monte Nuovo, in the Campi Flegraei, and in Iceland, containing free silica to the amount of 28 per cent. If the separation of quartz from melted masses were possible, it might be expected to have taken place here. Quartz crystals do, indeed, occur in this lava, but more frequently at detached surfaces than embedded in the mass. Quartz crystals, several inches long, in open fissures, must have been formed subsequent to the solidification of the lava, and assuming the igneous origin of this quartz, it must have been liquid after the much more fusible matrix had solidified, and become fissured by its contraction. It appears, therefore, that the quartz crystals at the surfaces of separation must have been formed in the wet way after the solidification of the lava; and there is no reason for supposing that the small quartz crystals, imbedded in the lava, have originated in any other way. Nor is there any apparent reason—assuming the crystallization of quartz from melted trachytic lava—why the whole amount of free silica in this lava, which is disproportionately greater than that of the quartz crystals in it, should not have crystallized during the solidification. Since there is no chemical affinity between silica and felspar, there could not be any chemical obstacle to the separation. Indeed, a thorough consideration of all the facts connected with the occurrence of quartz in rocks inevitably leads to the inference, that the opinion of its separation in the igneous way cannot possibly be maintained.

Trachytic lava is the only rock, containing an excess of silica, of which the igneous origin is certain; and if it appears that the excess of silica in this rock has not been separated during solidification, no ground remains for the opinion that the quartz occurring in other rocks has originated in such a way.

When an acid—dilute sulphuric acid, for instance—is mixed with indeterminate quantities of different bases—alumina, peroxide of iron, lime, magnesia, and alkalies—insufficient for saturation, the solution deposits, on evaporation, besides simple salts, several double salts, such as potash and iron-alum, sulphates of potash and magnesia, and of soda and magnesia. Such a mixture of sulphates and free sulphuric acid may be compared with a crystalline rock containing free silica. The above-mentioned lavas, from which trachytic porphyry has originated, were undoubtedly homogeneous melted masses, in which the bases existed as silicates with excess of silica. If the crystallization of the rock was effected by the action of water, the crystallization of the felspar would be accompanied by separation of silica, so that the latter might then crystallize in the spaces left between the felspar crystals, as is actually the case with granite; and so, likewise, quartz crystals might sometimes be imbedded in felspar crystals formed at the same time.

As in the instance of the mixture of sulphates, simple and double salts crystallize together, the crystallization of simple and compound silicates may be supposed to take place in the lava in question. However, simple silicates are seldom met with in granitic rocks, andalusite and cyanite are the only ones. But when it is remembered that alkaline and calcareous silicates, however diverse their relative amounts, would almost always appear as compound silicates, on account of the almost endless modes in which they combine with aluminous silicates; further, that the silicates of magnesia would likewise enter into as great a variety of compounds with silicates of alumina, protoxides of iron and manganese, and with the alkaline silicates over and above the amount requisite for the production of felspar, giving rise to the production of various kinds of mica; and that other portions of the several silicates might produce accessory minerals; there remains no doubt but that from such a mixture of silicates with excess of silica, crystalline rocks, consisting of compound silicates, may be produced, and that only in a few cases simple silicates would remain.

This would be the case, other conditions being similar, with all masses consisting of silicates. Sedimentary silicate rocks, as well as those which have been erupted in a state of fusion, may, in such manner, be converted into crystalline rocks.

It should also be remembered, that the slags of metallurgic operations never contain crystallized quartz, although the ores frequently contain a considerable amount; and it is not unfrequently added in the smelting.

It may be urged, that the difference of mass between granitic rocks and lava-streams, and the consequent difference in the rate of cooling and time of solidification, would account for the difference between these rocks in respect to quartz, insomuch as its crystallization would be much more probable in the case of the granite. But there are granite dykes and veins of such dimensions that, if erupted in a melted state, they must have solidified much more rapidly than ordinary lava-streams. Thus, in clay-slate, granite veins occur which are but one or two inches, and even less, in thickness. At the Rehberger Graben, at the south side of the Brocken, fine-grained granite extends, in sharply defined ramifications, into the hornstone, and frequently the veins become as thin as ordinary writing paper.* In such instances as these, the possibility of gradual solidification from a melted mass is altogether out of the question.

In order to illustrate the impossibility of the production of veins in this way, melted tin, lead, and zinc were poured into channels cut in sandstone slabs.† The results showed that the length of metal solidified in the cylindrical channels was proportionate to their diameter, and the length increased the hotter the metal was and the quicker it flowed. The greatest length of such a cylinder, 4 lines broad and 2·5 lines thick, was 8 feet. These dimensions, compared with those of a granite vein as thin as paper, will suffice to show that these veins cannot be of igneous origin.

Some adherents of the Plutonic theory recognise these difficulties, and endeavour to remove them by assuming that the rocks, into the narrow fissures of which, they consider, melted masses have been erupted, were at the time heated almost to the melting point. This assumption might indeed be maintained if granite veins did not occur in any other rocks besides granite; for if granite were originally a melted mass, it is just possible that during the solidification fissures might be formed and liquid portions might be forced into them while the mass was still hot. But there are granite veins in sedimentary rocks, such as clay-slate. For instance, the transition clay-slate of the Rhine, which is at least four miles thick, and a very bad conductor of heat, is traversed throughout by granite veins, and it could not have been so heated by contact with an underlying melted mass of granite, that this could be injected into the whole mass.

Those who consider that the constituent minerals of granite have been produced from a melted mass also maintain the conversion of sedimentary rocks into crystalline rocks in a similar manner. Thus, if clay-slate were heated to redness, it would, according to this hypothesis, undergo such a metamorphosis. But in this case clay-slate ought always to appear crystalline, where it is in immediate contact with granite, which is supposed to have been originally melted. But there are numerous instances in which this is not the case. Thus, G. Rose [*] states that on the shores of the Irtysch, in the Altai, the granite overhangs and covers clay-slate. Everywhere the junction of the two rocks is sharp and distinct. Nowhere is any alteration perceptible at the surfaces of contact. If this granite were melted originally it must have been very liquid to have flowed over such a wide extent of clay-slate. At the same time it must necessarily, in such a state, have penetrated fissures in the underlying clay-slate, forming granite dykes or veins. G. Rose describes large dykes that traverse these rocks; but the granite of these dykes is characterized by containing white mica; while that of the adjoining granite is black. Consequently the granite in the dykes and that overlying the clay-slate, have not a common origin, and consequently the possibility that this granite flowed in a melted state over the clay-slate falls to the ground. The effect produced by melted lava upon fragments of clay-slate will be considered in the chapter upon metamorphic rocks; and the fact that clay-slate may be converted into granite, though not by igneous action, will also be pointed out.

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* Hofmann.—Pogg. Annal. xvi, 526.

† German edition, ii, 739.

None of the facts that have been stated above admit of being reconciled with the opinion that crystalline rocks have acquired their crystalline development by igneous action. Even if these rocks were erupted in a melted state, their crystalline development must, as in the case of lava, have been the result of the action of water subsequent to the solidification and cooling of the mass.

With regard to the trachyte-porphyry lava, it is certain that it was brought to the surface as a melted mass. As its composition agrees so closely with that of granite, it would seem possible that this latter rock may have been erupted as a melted mass. But as the trachyte-porphyry lava solidified as an amorphous mass, and for the most part still retains this condition, so, likewise, the melted masses from which granite may have originated, would have solidified in the amorphous state. If granite could, under any circumstances, originate directly from a melted mass, it might be expected that lava, containing large amounts of silica and of potash would, sometimes at least, present the characters of a fine-grained granite.

Whether the trachyte-porphyry lava acquired its crystalline development during, or immediately after, its solidification, or whether this was acquired at a subsequent period, there can be no doubt that the rocks resulting from this change would be analogous to granite in point of fusibility, for the amount of silica separated from them, as quartz, would be as great as that in granite. But the compounds of silica with bases are much more fusible than silica itself in the state of quartz. This is an instance of the general law that the fusibility of homogeneous masses is considerably altered, when their constituents in virtue of chemical action enter into a new state of combination, or in other words, when amorphous substances become crystalline. In almost all instances substances become less fusible after such a metamorphosis. Thus, granite is much less fusible than an amorphous mass of the same quantitative and qualitative composition; and the granite itself is still less fusible the coarser its texture. The Vesuvian lava presents this character in a very remarkable degree. The heat requisite for melting it, after the very difficult fusible leucite has been separated, is certainly greater than that which it had in flowing from the crater.

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[*] Reise nach dem Ural, i, 586.

When crystalline rocks are not in conformable position with regard to other rocks, or when they are situated between other rocks, there is reason for assuming that the crystalline rocks have been thrust upwards. The former case was observed by v. Buch,* in the augitic porphyry of the Fassathal. Near Colfosco an augitic rock underlies a very considerable mass of thin layers of grauwacke, black limestone, and clay-slate, upwards of twenty feet long, which must have derived that rock from the interior of the earth. Below Sotto-i-Sassi a great part of the dolomite layers are separated from the principal mass and surrounded by augitic rocks. The arrangement of these rocks is very similar to that of the portions of red sandstone surrounded by dolerite, at Salisbury Crag, described by Hutton and James Hall; also to that of the dolerite at Stirling Castle, described by MacCulloch. The beds of red sandstone and of shelly limestone occurring in the neighbourhood of the Fassathal are dislocated, and are also at such different heights, varying from 900 to 7200 feet, that these detached portions cannot be reduced to any common level nor even to a common fall; but wherever these sandstone and limestone beds occur in such positions they are covered with dolomite.

It would appear, therefore, that all these beds, together with the dolomite, were thrust upwards by the augitic porphyry, for it is not easy to perceive how this could pierce these strata without thrusting them upwards. This elevation of the augitic porphyry was subsequent to the formation of the red sandstone and limestone beds. It likewise raised and pierced the red porphyry. According to v. Buch's view, it was not merely a single augitic rock, but the whole surface of the district that was raised. The whole chain of the Alps, or at least the limestone Alps, was elevated by augitic rocks. He believes, also, that a similar action has taken place in the Thuringian forest. Here, also, where the mountains consist of porphyry, rocks have been elevated over fissures. In this respect augitic porphyry and basalt have played the same part.

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* Annal. de Chim. et de Phys., xxiii, 276.

This hypothesis is founded by v. Buch upon the phenomenon of fissures, and upon a knowledge of the substances discharged from them during volcanic eruptions. Every volcanic eruption, even of the smallest extent, finds vent not from a round crater, but from a longitudinal fissure. But as the liquid mass is discharged continuously only where there is the least resistance, while it soon solidifies in the other parts of the fissure and prevents further discharge, the stream of lava always appears to issue from a round crater.

In these views v. Buch was evidently guided by analogous phenomena, which in all scientific investigation is a meritorious course. But his followers did not rest here. They disregarded the rapid solidification in narrow fissures, and did not hesitate to assume that melted granitic masses could be forced up through the most minute fissures. But this is not an antiquated opinion, belonging to a period when dazzled by the connection with volcanic phenomena it was supposed that the key to all phenomena of fissures had been discovered. It is one that is yet held, and even in the annual address to the Geological Society of London in 1847 it was stated, that granite veins no larger than thin wire have originated by the injection of a melted mass. Consequently, adds the speaker, not only must the pressure have been very great, but also the heat and liquidity of the mass.

After attention had been directed, by the above-mentioned observations, to the dislocation of stratified rocks in the vicinity of crystalline rocks, similar phenomena were observed at many places. American geologists describe very remarkable instances of this kind in the slightly-inclined Silurian red sandstone of Lake Superior, surrounding the cupriferous trapp rocks. At both sides of the trapp these sandstone layers are tilted up.*

The transition formation on both sides of the Rhine offers a very favourable opportunity for studying the effects of volcanic

* Albrecht Müller.—Verhandl. der naturforsch. Gesellsch. zu Basle, Heft. iii, p. 416.

elevation, and for comparing them with other phenomena of elevation which are ascribed to volcanic action. Upon the left side of the Rhine, in the neighbourhood of the Lake of Laach, and in the Eifel, there are a number of extinct volcanoes, some of them with very large and well-developed lava streams, that have flowed from craters which are distinctly recognizable, though rarely perfect. Upon the right side of the Rhine such extinct volcanoes do not occur. On both sides of the Rhine, however, there are a great number of basaltic cones; which, upon the left side, are for the most part intimately connected with the volcanoes. Trachytic or phonolitic cones occur less frequently upon the clay-slate rocks.

The clay-slate strata adjoining these cones do not anywhere present signs of dislocation or fracture; consequently these cones had no influence upon the elevation of the clay-slate. If, however, they were erupted, it must be assumed that they issued as melted masses, like lava, through fissures; for then only would it be possible that they could have risen without essentially disturbing the adjoining strata. In this case, the adjoining rock must have presented indications of the action of heat. But no such indications are to be found at any part of the contact between the crystalline rocks and the clay-slate.

The question why the stratified rocks associated with crystalline rocks are, in some instances, dislocated, and in others not, still remains to be satisfactorily answered. If solid masses, lying under the sedimentary rocks, were elevated, the latter must also have been elevated, fissured, and tilted up. If, on the other hand, there were fissures in the sedimentary rocks, then melted masses rising, as in volcanoes, would not have caused any dislocation of the sedimentary rocks. Such different effects of masses forced up above the surface, depending, as it would seem, upon the solid or melted state of those masses, might serve as a clue for explaining the absence of dislocation in the clay-slate strata adjoining the cones of crystalline rocks in the Rhine district. Thus it might be assumed that only melted masses were forced up through fissures in these strata, which, belonging to the oldest formation, would be nearer to the melted mass which is supposed to constitute the interior of the earth. It might, on the other hand, be assumed, that where the clay-slate formation is covered by a series of strata belonging to subsequent periods, the melted masses, in rising from below, were solidified. It might further be assumed, that the upward pressure gradually increased sufficiently to force up these solidified masses, and thus to fissure and tilt up the more recent strata. However, no one can be more sensible than myself of the fact that these opinions are merely tentative hypotheses, which have no claim to be regarded as an adequate explanation of the different phenomena in question.

The theory of igneous origin of crystalline rocks is quite inadequate to account for the changes that take place in these rocks, after the production of the original constituent minerals, and which consist in the alteration of those minerals, displacement of one substance by another, or production of new minerals by the introduction of new constituents. According to this theory, when the rock has cooled no further process of alteration or production should be expected to take place. Herein lies the great defect of the igneous theory—that it ascribes to a rock, once produced, an unalterable permanence, until such time as it may become subject to atmospheric influences;—that no distinction is made between the processes by which different effects are brought about.

The difficulty of reconciling the occurrence of hydrated zoolitic substances in many crystallized rocks with the igneous theory, has been felt by its supporters. But, instead of meeting this difficulty by the assumption that anhydrous minerals may, by subsequent chemical action, become converted into hydrated minerals—an assumption which would be supported by the conversion of anhydrous felspar into hydrated kaolin—it has been assumed that hydrated minerals have been produced at a red heat under the influence of great pressure. But even granting the bare possibility that zeolites, occurring deeply imbedded in crystalline rocks, may have originated in this way, it is still impossible to admit the same with regard to zeolites that occur at the surface of these rocks. Here, then, is a fact that is inconsistent with the opinion that the crystalline rocks originate from a melted or red hot mass protruded from the interior of the earth. No attention was paid to the fact, that in masses of lava even of considerable magnitude, no zeolitic minerals occur. But, when analogy fails — when rocks, that are known to have originated from melted masses, are in vain searched for, substances that occur in other rocks to which a similar origin is sought to be ascribed—the clue that would lead to a correct explanation of phenomena is lost.

The assumption that the production of minerals from melted masses took place only when, after they had cooled, water gained access to them, an assumption which is supported by the fact that the older lava alone contains imbedded crystalline minerals, removes at once the difficulties and contradictions with which the igneous theory is embarrassed. By such a mode of alteration, the simultaneous or successive production of hydrated and anhydrous minerals, the subsequent conversion of either one into the other may be consistently assumed to take place. Examples of such alterations have already been given.*

There is scarcely any crystalline rock in which iron pyrites does not occur to some extent. Thus granite, gneiss, syenite, mica-schist, chloritic-schist, porphyry, basalt, diorite, dolerite, trachyte, hornblende rock, all contain this mineral not only upon surfaces of fissures, but also imbedded in the rock. Near Kongsberg entire beds of micaceous and hornblende-schist frequently occur impregnated throughout with metallic sulphides, chiefly iron pyrites.

This mineral is disseminated throughout the rock in such minute particles, that its presence becomes recognizable only after it has been decomposed by exposure to the atmosphere.

Iron pyrites may, indeed, be prepared artificially at a temperature below redness. At a red heat this mineral loses one-half of its sulphur, and, consequently it is assumed, upon the igneous theory, that this was prevented by the influence of great pressure; a resource that is always adopted in any case of difficulty.

The production of iron pyrites in the wet way is, however, a demonstrated fact.† The very frequent and abundant occurrence of this mineral in sedimentary rocks, and especially in those containing organic remains, such as the brown-coal and coal-beds, does not admit of the assumption of any other mode of production. In rocks that originate from melted masses, organic remains, which are an essential condition of the production of iron pyrites in the wet way, would be absent. But so soon as vegetation commences upon such rocks, and the annual decay of plants produces a superficial coating of mould, the water penetrating the rocks carries with it organic substances, and the conditions for the production of iron-pyrites are then complete. Oxide of iron is not wanting in these rocks, and the presence of sulphates has also been proved.‡ Here then is a case of the subsequent production of a mineral which could not take place until the necessary material —organic substance—was provided.

Wherever there is a subsequent production of minerals amongst others previously existing it is necessary to suppose that there was space for their formation. But the substances which constitute such subsequent productions are not always introduced into the rock, and the change may consist merely in the transformation of existing materials. Thus, in the production of iron pyrites, the organic substance introduced into the rock serves merely for the reduction of the oxide of iron and the sulphates present in it. The oxygen of these substances combines with the carbon and hydrogen of the organic substance producing carbonic acid and water, which are removed, and thus the iron-pyrites occupies less space than the substances from which it has originated.

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* English edition, ii, 140, 147—Felspar, with the form of zeolites—145—Natrolite, with the form of elæolite.

† English edition, i, 162.

‡ Ibid., i, 417.

In many cases of the subsequent production of a mineral, space is provided for it by the displacement of some other mineral, as in the case of the frequent displacement of pseudomorphs. When the displaced mineral is amorphous, the replacing mineral would, if it crystallized, present its proper form. Such cases of displacement cannot be recognized mineralogically. Neither can displacement be recognized when the replacing mineral is amorphous.

It is still questionable whether quartz is displaceable by iron pyrites.* But pseudomorphous white iron-pyrites, with the form of calc-spar is known, and consequently it is possible that iron-pyrites may have been deposited in rocks containing carbonate of lime by the displacement of this substance.

Decomposition of Crystalline Rocks.—As a general rule the amorphous, or imperfectly crystallized mineral constituents of a rock, are more prone to alteration than the crystalline portions of the same mineral imbedded in the mass of rocks. This alteration always commences with chemical combination with water. Some crystalline rocks, such as granite, separate during their alteration into masses of various size. In the case of basalt, a kind of stratification becomes apparent when it is entirely converted into an earthy, pulverulent mass.

The decomposition and alteration of rocks may be entirely effected by the oxygen and carbonic acid absorbed from the atmosphere by water. This alteration always commences at the surface, and gradually extends inwards. When carbonic acid is the only decomposing agent, and it has a subterranean origin, the decomposition takes place along the whole extent of the rock with which the exhaled gas comes in contact. In this case the alteration commences below the surface and gradually extends upwards.

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* English edition, ii, 467.

In this process of alteration, oxygen converts the protosilicates of iron and of manganese into peroxide compounds; carbonic acid decomposes the alkaline and earthy silicates, the alkaline carbonates resulting from this action being immediately carried away by the water. When the decomposition of silicates by carbonic acid is completed, the earthy carbonates are dissolved and removed by the water, as bicarbonates. In consequence of this decomposition and abstraction of substance from the rock, its coherence is diminished; it becomes friable, and finally passes into an earthy mass.

The oxidation of protosilicate of iron in rocks, by oxygen dissolved in the water permeating them, being opposed to the reduction by organic substances, would be stopped or retarded when the water contained both oxygen and organic substances. The maximum of oxygen absorbed by water, under ordinary circumstances of pressure and temperature, amounts to only 0·065 by volume, or 0·00009 by weight. This quantity of oxygen would convert 0·000035 carbon into carbonic acid. So that when water contains only so much organic substance as is equivalent to this quantity of carbon, the oxidizing action of the water upon the protosilicates of iron would be reduced to null, independent of the fact that the hydrogen of the organic substance likewise exercises a reducing influence.

When the rocks are destitute of vegetation, the water permeating them would exercise a maximum oxidizing action. This would also be the case with mountains constantly covered with snow, a portion of this snow being melted during the warm part of the day. This melting is known to take place to a much greater extent in glaciers. The rivers issuing from glaciers show what enormous quantities of water are thus brought in contact with the rock upon which these ice-masses rest. The low temperature of the water facilitates the absorption of atmospheric oxygen, consequently the water permeating the underlying rock, would exercise a considerable oxydizing action.

Owing to the situation of the glaciers in the high valleys of the Alps, and the considerable fall of the rivers issuing from them, the glacier water, penetrating the underlying rocks, follows a subterranean course, and appears at lower points as springs. As the water is discharged from these springs, fresh oxygenated water is supplied from the glaciers so long as the melting of ice continues.

Such springs, originating from glaciers, occur abundantly in the Alps, and may be easily recognised by the low temperature of their water.* About 200 yards from the baths of Leuk there is a periodic spring, which has four outlets, all situated close together; the water is ice-cold, and so abundant that it might be employed for driving a mill. The water of this spring generally begins to flow in June, and ceases at the end of August. The quantity of water is greater the warmer the summer is. It is very probable that the water of this spring originates from the Lötsch glacier, for when at the commencement of the warm weather, the river fed by this glacier begins to flow, the periodic spring begins to flow some three days afterwards, and ceases again some three days after the river ceases to flow. There are many springs with ice-cold water in the neighbourhood of the upper Grindelwald glacier, and in the valley of Lütschine, between Interlaken and Grindelwald, as well as at the Spital-Matte, at the northern foot of the Gemmi. The water of all these springs originates most probably from glaciers.†

There can be no doubt that the oxidation of minerals by water containing oxygen, and free from organic substance, plays an important part in the decomposition of crystalline rocks in the Alps. The great diminution of the solidity of such rocks, in consequence of the oxidation of protosilicates of iron, is illustrated by basalt, melaphyr, etc., and all rocks containing any considerable amount of these silicates. In proportion as their dark colour passes into ochre-brown they lose their coherence, and when the oxidation is complete they fall into a pulverulent mass. In this alteration the silicates of lime likewise take part, and hence those rocks which contain much protosilicate of iron, and also silicate of lime, are the most prone to decomposition.

Limestone containing carbonate of iron likewise undergoes the same kind of change by oxidation; and when the amount of carbonate of iron is large, the disintegration of the rock is brought about by the conversion of this carbonate into hydrated peroxide of iron.

The immense accumulations of detritus at the lower ends of glaciers illustrate the magnitude of the alteration of rocks in the Alps by chemical and mechanical actions.‡

The water of all streams originating from high mountains, upon which there is little or no vegetation, exercises the same oxidizing action upon rocks as the water of the glacier streams in the Alps. As the water of these streams flows over the surface of the rocks so far as the fall is considerable, it penetrates into the rocks either by absorption, or through fissures and cracks, towards the foot of the mountains. Thus large masses of water follow a subterranean course, and the oxidation extends to considerable distances. The disintegrated portion of the rock is carried away mechanically by the flowing water, together with the detritus.

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* Physical, Chemical, and Geological Researches, etc., by G. Bischof. London, 1841, i, 67.

† Ibid., p. 78.

‡ Ibid.

The case is different at the lower portions of the course of such streams. Here vegetation increases, the water flowing less rapidly, extracts organic substance from the decaying remains of plants, the bed of the stream is filled with detritus, which hinders the penetration of water into the rocks, and the oxidizing action of the absorbed oxygen is compensated by the reducing action of the dissolved organic substance. If the streams fall together into a river flowing through a valley rich in vegetation, the water becomes more and more charged with organic substance. This is especially the case when the course of the river passes through uninhabited and uncultivated districts, where the vegetation annually decays, and where, as in the American rivers, large masses of drift-wood are carried into them.* It has already been shown what large quantities of organic substance are present in the water of the Nile, and of the Rhine, although the course of the latter river is for the most part through cultivated districts.†

The analysis of the water of the Vistula,‡ which traverses a considerable extent of uncultivated land, shows the presence of 2·54 dissolved organic substance in 10,000 parts of water, and that the substances suspended in it contain 23·21 per cent. organic substance and water.

It is evident that in the presence of such considerable amounts of organic substance in the water of rivers, the oxidation of rocks must be entirely prevented; and, moreover, that the peroxide of iron, originating from a previous oxidation of minerals containing protoxide of iron at higher points of the river's course, in the detritus and suspended substances, will again be reduced. This was found to be the case in the analysis of the suspended substance of the Vistula. The iron dissolved by hydrochloric acid was for the most part in the state of protoxide.

This is another instance of the cyclical change which is so frequently observed in nature. The water flowing from the mountain heights, where there are no organic substances, exercises at first an oxidizing influence, in virtue of which the rocks over which they flow are decomposed. The suspended substances carried down by these rivers, and the detritus swept along their beds, comes, after a time, in contact with organic substances, by means of which the peroxidized iron compounds are again reduced. Consequently, the iron thus carried into the sea is for the most part in the state of protoxide, either combined with silica or with carbonic acid, the silicate being suspended, and the carbonate dissolved in the water.

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* English edition, i, 295.

† Ibid.

‡ German edition, ii, 1517—1591.

At some point of the depth to which meteoric water may penetrate into rocks, there cannot be any decomposing action exercised by oxygen and carbonic acid, because the whole of these substances would be separated from the water, and consumed during its passage through the upper portions of the rocks. But this water will have extracted from the decomposed rocks soluble substances, and thus have acquired the capability of producing other changes at greater depths. An instance of this kind is furnished by the analyses of the Taunus slates by List, and will be referred to subsequently.

There may also be an interchange between the substances dissolved in the water and certain constituents of the yet unaltered rock, and thus new minerals may be produced, as is shown by the pseudomorphs occurring so frequently in rocks. It may so happen that the water deposits substances having a greater degree of hardness than the substances removed, and that the solidity of the rock would be thus increased, as well as its appearance of freshness. This would be the case when water deposits silica in the interstices of rocks adjoining dykes, and removes other substances of less hardness. This silicification is a very frequent phenomenon everywhere, and is the more readily intelligible since alteration and decomposition, attended with elimination of silica,* are very frequent in rocks. When the eliminated silica is not deposited immediately, but is removed in solution by water, this silicification may be effected at considerable distances.

By the total decomposition of crystalline rocks, the various kinds of clay are produced, which are generally carried away by water, and are either deposited in river-valleys or swept into the sea. More rarely, these residua of clay remain at the place occupied by the original rocks.

The silicates of which clay consists generally contain the soluble modification of silica, and are therefore decomposable by acids—

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* English edition, ii, 172.—Conversion of felspar into mica.

at least, partially. Some kinds of clay, however, are decomposed in this way only when they have been previously ignited. Consequently, the decomposition of crystalline rocks consists in a conversion of silicates, not decomposable by acids, into silicates that are more or less decomposable by acids. This is especially the case with those rocks containing felspar—orthoclase—with little or no lime. On the other hand, the rocks containing felspar with a considerable amount of lime—augitic labradorite rocks—are, to a certain extent, decomposable by acids.

It is to the amount of decomposable silicates of alkalies and lime in the clay, that the high fertility of this earth must be ascribed; for these are gradually decomposed by the long-continued action of carbonic acid, in the same manner as they are decomposed rapidly by the action of strong acids. And in this way the substances so essential for vegetation are gradually eliminated.

In the southern districts of Brazil large masses of clay occur at the surface, which have originated from the decomposition of granite and granulite. This clay is very fertile, and constitutes the soil of the virgin forests, the rich vegetation of which is described by so many travellers.*

From the following analyses of clay it appears, as a general rule, that the silicates of alkalies and alkaline earths are only in subordinate proportion. This is a consequence of the partial decomposition of these silicates, and removal of their bases as carbonates during the alteration of the original rocks by water. The amount of alkalies in the clay of the St. Lawrence valley is, however, very considerable, and is nearly equal to that in some crystalline rocks—such as granite, for instance. Hence it may be inferred, that in the alteration of the rock from which this clay originated, only a small portion of the alkaline silicates were decomposed. Probably in this case, the mechanical action of water preponderated over the chemical action of substances dissolved in it.

The special consideration of crystalline rocks in the following chapters will be limited exclusively to those of which analyses have been published. A more complete enumeration of crystalline rocks, with their varieties and transitions, such as is met with in works on geognosy, must be left for a future period of chemical geology, when these rocks shall have been subjected to adequate chemical investigation.

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* Pissis—Comptes rendus, 1843. No. 1.

CHAPTER XLVIII.

METAMORPHIC ROCKS.

IT is customary to include under this term, rocks that present stratification, and have also a crystalline structure. The former character they have in common with sedimentary rocks; in the latter character they resemble the crystalline rocks, so that they appear to have a sedimentary origin, and to have been rendered crystalline subsequently.

This definition does not, however, comprise those rocks which, during their conversion into a crystalline condition, have had their stratification obliterated; as, for instance, is the case with dolomite, which has originated from sedimentary limestone; nor does it comprise those rocks which have originated from crystalline rocks by an alteration that has obliterated their crystalline character.

In general, therefore, the term metamorphic must be understood as applied to such rocks as have originated from others by alteration. These may be subdivided into four classes.

1. Crystalline rocks originating from sedimentary strata with retention of the stratification.
2. Crystalline rocks originating from sedimentary strata with obliteration of the stratification.
3. Crystalline rocks originating from other crystalline rocks.
4. Amorphous rocks originating from crystalline rocks.

The indications of metamorphosis in rocks are stratification combined with crystalline structure, gradual passage of a sedimentary stratum into a crystalline rock as part of the stratum, imbedded masses of the original rock in the crystalline portions, the occurrence of fossil remains in both, pseudomorphs in the altered portion, presenting the forms of minerals that occur in the unaltered portion. The knowledge of pseudomorphs is, on the whole, an excellent means of recognizing where metamorphic processes have taken place. When pseudomorphs show that a mineral, B, may originate from another mineral A, it is possible that, under suitable conditions, all minerals corresponding to A, may undergo such an alteration in the rock where they occur.* This may be the case even when the former mineral is not in a crystalline state, but exists in the rock as an amorphous mass.† In the latter case, this conversion cannot be indicated by pseudomorphs, for the altered mineral would then appear either as an amorphous mass, or with its proper crystalline form.

Occurrence.—Metamorphic rocks are of a very frequent occurrence. Including under this term, also, those rocks that have originated from sediments by the alteration of one or other constituent, every rock would, strictly speaking, be a metamorphic rock. Since, moreover, the sedimentary rocks constitute by far the greater part of the known crust of the earth, metamorphic rocks, so defined, would be the most frequent of all.

This may be illustrated by the following examples:—

Sauvage ‡ found in clay-slate, chlorite disseminated as an extremely fine powder, and mixed with oxides of iron and manganese, as well as with an organic substance that gave the rock a greyish and blueish-grey colour. He also found in this rock anhydrous silicate of alumina generally as shining laminæ. Both these constituents may be regarded as having pre-existed as suspended particles among the material from which the clay-slate was formed. This view would be confirmed if chlorite powder and laminæ of silicate of alumina were found among the deposits from rivers. However, it is not probable that the latter would be anhydrous. There is nothing inconsistent with the opinion, that the chlorite was produced after the deposition of the suspended material, the persilicate of iron being meanwhile reduced to protosilicate by the action of organic substances. The association of peroxide of iron and organic substance with this chlorite favours this view, and the production of chlorite in the wet way is unquestionable.§ In like manner, it may be supposed that the anhydrous silicate of alumina may have originated from hydrated silicate, just such an alteration having been shown to take place in the conversion of zeolites into felspar ‖ and in other cases.

If the latter view is the more probable and correct, the clay-slate originating from the suspended material in the sea, would be a metamorphic rock. But even if the constituents of clay-slate, as it now occurs, were ready formed in the suspended material, the conversion of this loose sediment into a compact rock, must be

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[*] English edition, i, 51.

[†] English edition, i, 50.

[‡] Ann. des Mines. (4), vii, 411.

[§] Ibid., ii, 415.

[‖] English edition, ii, 140—147.

regarded as a metamorphism, since the introduction of a cement would be necessary, and this might be supplied either directly from the sea-water, or by a partial solution of the sediment.

It has already been remarked * that the reduction of persilicates of iron appears to be an essential element of the metamorphism of rocks. Thus, if these silicates in the suspended material of the ocean were reduced to protosilicates, this would be the first stage of the metamorphism by which the material for the production of a great number of different compound silicates would be provided. A portion of the silicates contained in the finely divided sediment would then combine and produce compact masses. A mass of clay, for instance, consisting of a mixture of silicates of iron, alumina, magnesia, and alkalies, might, after the reduction of the persilicates of iron, yield mica which is so frequently met with as a constituent of clay-slate.

The brown clay deposit of rivers, and the similarly-coloured deposit from the sea, contrasted with the green-coloured clay-slate that has originated from these deposits, should long since have suggested an inquiry as to the cause of this difference of colour. Certainly such chemical questions could not be raised so long as it was not customary to seek the aid of chemistry in connection with geological subjects. But it cannot now be doubted that the sediment from which clay-slate has originated, consisted, like those of the present time, essentially of persilicates of iron, with but small amount of protosilicates. These suspended substances afterwards came in contact with the algæ, and with the remains of marine animals, which abundantly furnished the conditions for the reduction of the persilicates of iron, and for the production of green-coloured slate-rocks.

Taking the above extended interpretation of the term metamorphic, the slate-rocks of all geological series in which the occurrence of fossil remains indicates their sedimentary origin, must be regarded as metamorphic rocks. Sandstone, also, and crystalline limestone would be comprised under this head, for the former could have been produced from sea-sand, etc., only by the introduction of a cementing material, and the latter are merely crystallized sedimentary rocks. Moreover, crystalline masses of all kinds that have originated from amorphous masses, either with or without the introduction or separation of constituents, must be included among the products of metamorphism.

Formation.—Those who adopt the Plutonic theory, consider that the crystalline minerals in metamorphic rocks have been produced by the action of heat, but in order to account for the undisturbed stratification, they are at the same time compelled to assume that the crystallization may take place when the strata are simply heated to redness. This heating is supposed to have been effected by the protrusion of melted masses which, it is supposed, furnished the material for the formation of the unstratified rocks.

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* See ante, p. 5.

Our examination of metamorphic phenomena commences with the alterations of sedimentary rocks that have actually been brought in contact with melted masses.

In the scoriæ and lava of the volcanic district of the Eifel and the neighbourhood of the lake of Laach, fragments of clay-slate and of grauwacke are often found imbedded.

In the immense masses of scoriæ at the Falkenlei, near Bertrich, I found, together with many small fragments of clay-slate, one that was nine inches long and two inches thick at the middle, tapering off at both ends, entirely imbedded in the scoria, but presenting scarcely any signs of alteration. It appeared only to have become rather more hard and sonorous, and at some parts it had a rather vitreous lustre. It was not vesicular, but a small splinter detached from it, and also imbedded in the scoria, was like all the other small fragments, vesicular. It seems, therefore, that the moisture and other vaporizable substances, that give rise to the vesicular condition, may escape from a fragment of some size without rendering it vesicular, even when the outer portions are softened by contact with the lava.

The clay-slate and grauwacke fragments in the scoria on the crater of the Mosenberg are very numerous, and generally appear to be altered by the action of heat, but I did not, in any instance, find so large a fragment as that above mentioned at the Falkenlei. I in vain sought in the scoria of the extinct volcano at Gerolstein for fragments of the transition limestone, or dolomite, that are penetrated there. Nor was I more successful in finding such fragments in the scoria or lava of the Bickeberg, near Essingen, which rises like an island above the transition limestone. Nevertheless, these results must not be regarded as quite conclusive.

The scoria and lava of the Roderberg, near Bonn, contain a great abundance of imbedded fragments of the rocks penetrated by this extinct volcano. Grauwacke and clay-slate fragments are met with in the lava, and in the erupted scoria that lie in large quantities on the edges of the crater. At one place, on the inner declivity of the crater, where the lava is laid open by a quarry, fragments of clay-slate, several inches in diameter, are met with. These are all red, appearing like burnt bricks, but they are rarely vesicular, and altogether so little altered in appearance that the red colour is the only indication of the influence of heat. On the contrary, there are fragments imbedded in the lava at the outer declivity of the crater that are not at all altered. At a lower point of this declivity there are pebbles, generally quartz, imbedded in the mass, and presenting a vitreous appearance at the surface, indicative of the action of heat. One of these quartz pebbles had a dirty yellow, vitreous coating, barely so thick as fine paper, and at some places there were patches of lava firmly attached, as if by fusion. The action of heat was perceptible only at the outer surface. On the contrary, in the ejected masses, especially on one side, quartz pebbles are met with, besides clay-slate fragments, often only as big as millet seed, but without any vitreous coating or any signs of alteration.

In like manner there are fragments of clay-slate and grauwacke met with, which are vitrified at the surface. These are sometimes of considerable size between the masses of scoria near Boos, in the Eifel. They appear as if they had been dipped into melted glass, but the thickness of the vitreous coating can scarcely be recognised at the surfaces of fracture. The interior appears, with the exception of the red fragments, so little altered either in colour, fracture, or compact character, that there is nothing to indicate the action of the heat to which they have been exposed.

On the Leilekopf, about two miles from Brohl, on the Rhine, where a large bed of rapilli, volcanic sand and scoriæ are opened up by a quarry, the latter contain numerous fragments of clay-slate, which are, with few exceptions, more altered than I have observed them any where else. Some are reddened, generally very vesicular, and sometimes quite like pumice-stone. Quartz pebbles, that are also met with, are so friable that they may be crumbled between the fingers.

It will be evident from the above remarks that even when the influence of fire has unquestionably been exercised upon rocks, its effects cannot always be recognised.

The supporters of the Plutonic doctrines must account for the fact that the grauwacke and clay-slate fragments that have been so heated by the scoria, in which they are imbedded, as to have become soft, as is shown by their vesicular character, have not during the subsequent slow cooling undergone metamorphosis. More favourable conditions for such metamorphism, if it were at all possible, could not be found any where. A cone of scoria like the Falkenlei, which since it is laid open to the depth of 160 feet, is known, with certainty, to consist entirely of scoria and lava, though it is not known how far it may extend down below the surface of the grauwacke, would certainly have taken a very long time to cool.

Breislak * states that there is lava at Etna, which after the lapse of 25 to 30 years was still hot and smoking. From the result of an experiment referring to the cooling rate of a melted globe of basalt, two feet in diameter, I have calculated that a lava stream 400 feet thick would require for its cooling 22 years.† If, therefore, the Falkenlei extends only 240 feet below the surface of the grauwacke, it would have taken this time to cool. Then, if within this time the clay-slate, containing the elements of felspar, has not given rise to the production of a single crystal of this mineral, although felspar crystals have really been produced from a melted mass at the Sangerhausen copper-works,‡ there is good reason for doubt whether such crystals could possibly be produced in this way from clay-slate, however long the heat was continued. The occurrence of fragments of felspar partially melted and vesicular, in the scoria of the Falkenlei, cannot be brought forward in opposition to the above view, for it would be a very remarkable thing if such fragments should have been first produced by great heat and afterwards partially melted as the heat was decreasing. Therefore, there can be no doubt that these felspar fragments pre-existed just as much as the fragments of grauwacke, etc.

The burning of bituminous strata offers an opportunity of observing the influence exercised upon rocks by the long continuance of heat. In these cases, it is found that the bituminous strata become decolourized by the destruction and volatilization of the organic substance. The bituminous lias slate near Kirchheim, in Würtemberg, has become much altered, and assumed the appearance of Armenian bole. Ferruginous strata assume a variegated appearance. The sandstone of the coal-measures becomes streaked white and red. The shale of the same series at Wettin has retained its bluish-gray colour at the interior, and has become reddish at the outer surface. At Duttweiler and some places in Bohemia, the shale and plastic clay is at some parts reddened throughout like burnt bricks. Where they were situ-

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* Geologie i, 330.

† Die Wärmelehre des Innern unsers Erdkörpers, etc., p. 500.

‡ English edition, ii, 164.

ated near the burning beds of coal, they are converted into porcelain jasper, as at Duttweiler, near Saarbrücken, at Planitz in Saxony, at St. Etienne, near Lyons, etc.*

Zeuschner† speaks of diorite situated near Kattowice, in Upper Silesia, that is supposed to have originated from a former combustion of coal-beds. But, according to the information furnished to me by Nöggerath and v. Carnall, this rock is not diorite at all. Between the ordinary products of such action—porcelain jasper, burnt shale and earthy scoriæ—there are a few layers of fine sand and shale that have been intensely ignited, and are strongly coloured green by protoxide of iron; thus presenting a great similarity in appearance to compact diorite.

The rocks that are supposed to have undergone such plutonic metamorphosis do not present any vestige of such alterations as the above. The shale in the above instances, which resembles clay-slate so closely in composition, must have presented alterations similar to those presented by metamorphic clay-slate, if the latter had been produced by the same action of heat. Not a single crystal of felspar has ever been found in shale that has been altered by the combustion of coal in its vicinity. Nöggerath, who has examined several instances of this kind in the coal-measures of Upper Silesia, and in the brown coal deposits of Bohemia, has never met with any crystalline alteration of the rocks.

It cannot be urged, in support of the plutonic theory, that the time during which the influence of heat was maintained was too limited. The burning stratum near Duttweiler has been burning for 185 years; and if, during this time, no signs of any tendency to crystallization of felspar are presented, there is little reason for expecting that the crystalline separation of felspar would take place even after thousands of years.

The favourite hypothesis, that water-vapour has been the means by which the conversion of sedimentary strata into crystalline rocks has been effected, would long since have been rejected if attention had been paid to the actual effects produced upon rocks where water-vapour issues.

At Duttweiler, water-vapour issues from the fissures in shale so copiously, that in cold moist weather the whole valley is enveloped in thick mist. From some of these fissures water-vapour issues mixed with some sulphurous acid gas and atmospheric air, the temperature of which I found to be from 212 to 355° Fahr. But, with the exception of the above-mentioned alteration of the shale and the sublimation of sulphur and chloride of ammonium, no other effects are recognizable here.*

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* v. Leonhard—Basaltgebilde, p. 469, and Bronn—Handb. der Gesch. d. Natur. ii, 640.

† Jahrb für Mineral. 1838, p. 582.

The suffioni† produce no other alteration of the jasper and hornstone near Monte Rotondo, than the bleaching of the red and dark-green coloured masses, the dissolution of the compact structure, and the conversion of the rock into a cellular mass that ultimately falls to powder. The odourless water-vapour produces, according to Darwin's account, the same decomposing effects upon the trachyte of Terceira, the rock being converted into white earthy clay, silica being extracted and again deposited as hyalite. Junghuhn observed similar effects in the Telega-Leri, in Java, a swamp from all parts of which water-vapour issues.

Jeffrey's‡ experiments show that felspar is rapidly decomposed by water-vapour at the temperature of melting cast-iron, and becomes covered with a crust of silica; consequently, silicates cannot be produced in this way, for the action of water-vapour tends to bring about decomposition.

If the metamorphism of rocks by igneous action were at all possible, sedimentary rocks could be altered only in character but not in composition; for it is impossible to suppose that substances have been introduced and others removed from these rocks by sublimation. But the introduction and removal of substances does take place in the wet way. Therefore a sedimentary rock, the constituents of which are not definitely proportioned, may be converted in this way into a crystalline rock, consisting of minerals having a perfectly definite composition; for whatever excess of any constituents there may be would be separated by water, and whatever deficiency there might be would be supplied in the same way.

We now come to the consideration of those alterations of sedimentary rocks that are supposed to have been in contact with igneous masses.

If the crystalline masses filling dykes and veins were everywhere in their original condition, and if they were of igneous origin, it is probable that there would be places where the effects of heat would be recognizable. But, even on *à priori* grounds, it is evident that the conditions connected with an eruptive origin would generally conceal the proofs of such origin; for I have shown* experimentally that melted basalt undergoes a considerable contraction when it passes from the liquid to the crystalline condition. If the contraction was uniform in all directions, there would be, in a fissure one foot wide, an interval between the basalt after solidification, and the adjoining rock, of 2·6 lines at each side. Such vacant spaces could not have remained for a long time without being filled up. The water passing through them would have exercised a decomposing action upon the basalt and upon the adjoining rocks, depositing new substances both mechanically and chemically. These mechanical deposits, such as ochery clay, are generally met with between basaltic columns, and sometimes chemical deposits are also found. A striking instance of the latter kind is presented in a basaltic quarry near Leubsdorf, on the Rhine, where there is a layer of arragonite two or three lines thick between the basaltic columns. The insterstices between the basaltic columns might also be filled up in consequence of the decomposition of the surface of these columns; for in that case the crystalline character would be destroyed, and the volume of the mass increased, independent of the material furnished by the adjoining rocks.

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* Jahrb. für Mineral., etc. 1839, p. 512, et seq.
† English edition, ii, 16.
‡ Rep. of the Brit. Association, 1840.

The contraction of melted masses in consequence of their crystallization would afford an opportunity for the formation of saalbands which are actually met with in the vicinity of volcanoes. Thus, Necker de Saussure describes a dyke in the rocks of the Primo-Monte, on the side of Monte Somma, which presents a saalband of vitreous lava. According to Mackenzie the doleritic dykes in the island of Vidoe, near Iceland, have sometimes at their walls a more or less thick vitreous coating that gradually blends with the mass of the dykes. L. von Buch states, that in Teneriffe a basaltic dyke, twelve fathoms thick, traverses beds of red lapilli and pumice-stone, and has, at both sides, layers of scoriaceous fragments a foot thick, resembling saalbands.†

Several examples of saalbands in basaltic dykes are given by Leonhard.‡ However, these facts cannot be regarded as evidence either for or against the igneous origin of the basalt; for generally this rock and the adjoining rocks are so much decomposed, that saalbands might have been produced in this way without any possibility of its being determined whether they originated from the basalt, or from the adjoining rock, or from both.

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* Jahrb. für Mineral., etc., 1848, p. 1, etc.

† German edition, ii. 752.

‡ Loc. cit., i, 447.

The Erpeler Lei, a basalt quarry on the Rhine, that has been much worked, seemed to afford a good opportunity of studying the effects of its contact with clay-slate, but both rocks were so decomposed to the extent of several feet and converted into ochery masses, that the line of their junction could not be recognized.

Among a great number of basaltic dykes that I have examined, there was only one, situated at the Lachmühle, below Altenahr, which presented small saalbands, and where neither the basalt nor the adjoining rock contained hydrated peroxide of iron that had been separated by decomposition. At this place the basalt is in direct contact with the clay-slate; it presents spherical masses, and has an earthy appearance, but seems not to have undergone any essential alteration of its original colour. On the fracture surfaces there are frequently white radiated groups of acicular crystals that dissolve with effervescence in hydrochloric acid, and small crystals of calc-spar in cavities. A piece of this basalt immersed in dilute acid gave off a great number of bubbles, and seemed to be penetrated throughout with carbonate of lime. This basalt did not present any ochre-yellow spots, and the calc-spar crystals could not contain any sensible amount of iron, as they were colourless. After lying twelve hours in the acid, much protoxide of iron was dissolved besides lime. Therefore the decomposition had affected the silicate of lime, but not the protosilicate of iron. Associated with the spherical masses of basalt, there are greyish white argillaceous masses that have resulted from more advanced decomposition.

Fragments of the clay-slate in immediate contact with the basalt, and at distances of several feet from it, were not distinguishable from each other. The former did not present any signs of the action of heat, but between the cleavage planes there were thin layers of carbonate of lime, and in the whole mass of the rock there were places that effervesced with acids. In one fragment, taken some feet distant from the dyke, there were only two spots that effervesced with acids.

These deposits of carbonate of lime undoubtedly originate from water, that in permeating the dyke has taken up carbonate of lime by the decomposition of the basalt, and deposited it in the adjoining rock. The fragments of clay-slate in contact with the basalt were, when treated with acid, perfectly similar to those taken at a distance from the dyke. The slight alteration produced by the deposition of carbonate of lime might, however, be misinterpreted as an indication of the action of heat. Certainly this alteration results from contact with basalt; not, however, from contact with melted basalt, but from the decomposition of the basalt. Since this decomposition affected only the silicate of lime, this basalt dyke affords a rare opportunity of studying its influence upon the adjoining rock. If the protosilicate of iron were also decomposed, and if water had deposited hydrated peroxide of iron partly in the basalt, partly in the grauwacke, and partly between the two, then it would be uncertain whether these deposits originated from the basalt or from the clay-slate. The slight ochery colour of the surfaces of this rock undoubtedly arises from decomposed protosilicate of iron.

The place where I examined this basaltic dyke lies 25 feet below its outcrop, near which there are masses of ochery substance, which show that at this place there has been a second process of decomposition that affected the protosilicate of iron.

When it is remembered that the above-mentioned fragments of clay-slate imbedded in the scoria of the Falkenlei, and the similar fragments with vitrified surfaces at Boos, presented scarcely any alteration at the interior; when, also, it is remembered that even these alterations disappear in the course of time when such rocks are exposed to the influence of water, it cannot be expected that the clay-slate or the basaltic dyke would now present any signs of alteration they might have undergone in case the basalt was protruded as a melted mass. The adjoining rock would be in contact only with one side of the melted basalt; it could not become vesicular because the moisture would be able to escape towards the interior. If, also, there had been a vitrification at the line of contact, as in the case of the fragments above mentioned, the subsequent penetration of water, as soon as the mass had contracted to some extent, would have led to the decomposition of the vitrified crust. Although the vitreous condition opposes a considerable resistance to decomposition, it is not absolutely permanent, as is shown by the opalescence of window-glass in old buildings.*

Apparently, the effects of heat produced by the contact of melted basalt might be expected to be recognizable most easily when it is in contact with brown coal. The working of this mineral in the Vogelsgebirge, Westerwald, and Meissner, etc., afforded opportunities of examining the characters of the brown coal, plastic clay, etc., where they were in contact with basalt.

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* A fragment of old window-glass from the Cathedral at Cologne, which is in my possession, is not only dull, but in a high degree corroded.

At the latter place, where there is a layer of plastic clay, varying from six inches to five feet thick, between the brown coal and a colossal mass of basalt, the clay presents a columnar structure that extends even into the underlying coal. The clay columns are at right angles to the basaltic covering. In the Vogelsgebirge, near Ettinghausen, this columnar structure is recognizable to a distance of 2 or 2¼ feet from the under surface of the basalt. These columnar masses of clay are reddish brown at the contact with the basalt, and to a distance of several inches, but at a greater distance the colour becomes pale red or grey. Near the small town of St. Saturnin, in the Puy de Dôme, there is a basaltic mass spread out over a layer of clay, containing numerous vegetable remains, which appear to be carbonized, while the clay is hardened and rendered columnar to a distance of ten or twelve inches deep, being separated into small perpendicular prisms. The sandy clay over which the southern stream of the volcano of Gravenoir flowed, is yellow and reddish, indurated, very much fissured, and separated into parallelopiped portions.*

This columnar structure of the clay underlying basaltic masses that have flowed from craters certainly admits of the conclusion that even where craters cannot be recognized this phenomenon has the same cause.

The influence of the heat of basaltic masses is less evident in the brown coal itself. It has, indeed, been attempted to refer the greyish or pitch-black colouration, the conchoidal fracture, and the fatty lustre of the coal in immediate contact with the columnar clay, to the action of heat; but where the plastic clay has a thickness of five feet, the conduction of heat from the basalt to the brown coal to such extent as to produce any considerable alteration of the latter could not be expected, more especially since the clay in contact with the brown coal still contains water of hydration, and also traces of bitumen. I am therefore doubtful that the effects of heat could be traced at all in the brown coal situated under clay beds seven or eight feet thick.†

The previously mentioned‡ observations and experiments show that brown coal may undergo alterations which closely resemble those produced by heat, though they are produced by entirely different causes.

Since the bituminous wood imbedded in strata cannot, when covered with a layer of clay that excludes atmospheric air, become dry, it follows that no alteration can take place until it is exposed

* Leonhard—Loc. cit., ii, 277. † Ibid., ii, 292. ‡ English edition, i, 292

to the atmosphere. If the wood then does not merely dry, but also absorbs oxygen, it is conceivable that it may be converted into pitch coal in the layers of brown coal. The not unfrequent occurrence of foul air in brown coal deposits, shows that there is actually an absorption of oxygen in these deposits.* The occurrence of pitch coal in brown coal beds that have been brought in contact with basalt cannot therefore be regarded as any evidence of the influence of heat.

If, however, the plastic clay were fissured as at Meissner, access of air would be possible, and the drying as well as absorption of oxygen would be facilitated. So far as the heat of the basalt caused the fissured state of the clay, it may have been indirectly the means of converting the bituminous wood into pitch coal.

At Meissner the columnar coal and glance coal is found sometimes, although seldom, immediately under the plastic clay, and generally speaking the pitch coal is deeper down. But this contains much bitumen, while the glance coal contains less, and that in contact with the columnar coal contains only small traces. But where there is much bitumen, there cannot have been any great influence of heat exercised. Moreover, the varieties of altered brown coal do not in general present any distinct separation either among themselves, or from that which is not altered, but are intimately blended with each other, streaks of pitch coal extending into and through the brown coal.

At the Habichtswald the brown coal appears not to have been much altered where the basaltic dykes are only from four to six feet thick; but where they are ten or twelve feet thick, the coal is rendered columnar for a distance of some one or two inches.†

In Bohemia and at the Giant's Causeway, where a brown coal occurs in contact with basalt, it appears to be little if at all altered.‡

In geological works the alteration of rocks in contact with basaltic dykes is so frequently spoken of, that there may be some difficulty in doubting its reality. But it is not less frequently stated that, at such places of contact, no alteration can be recognized.§ From the fact that totally opposite alterations of rocks are ascribed to the action of heat, it is evident that a great part of the actual alterations of rocks are not due to the influence of heat. Sometimes it is supposed that a friable condition indicates the action of heat, sometimes the hard and flinty state of the clay-slate is ascribed to the cause. In the former case no regard is paid to the fact that bricks, porcelain, etc., instead of becoming friable, are hardened when burnt. All the fragments of slate or grauwacke imbedded in scoria that I have examined were not more friable, but harder, than the unburnt rock. The induration of shale may, however, be due to another cause. The conversion of slate into siliceous slate is certainly the result only of the infiltration of silica. This is an alteration that has taken place long after the filling of the fissures with basalt, and therefore cannot be ascribed to the influence of heat.

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* Leonhard.—Loc. cit., i, 293.

† Loc. cit., p. 286, et seq.

‡ Loc. cit., p. 308.

§ See Leonhard.—Basaltgebilde, p. 180.

The bleaching of red sandstone is generally regarded as an indication of the influence of heat, and it is strange that those geologists who hold this opinion do not hesitate to ascribe the red colour of clay-slate fragments, imbedded in scoriæ, to the action of heat also, although the colouring material in burnt slate and bricks is in both cases the same, peroxide of iron.

The bleaching of sandstone, coloured red with peroxide of iron, by the action of heat upon it, is, however, unintelligible. The reason why sandstone becomes bleached, consists in the removal of the peroxide of iron.* Organic substance in the water flowing between basaltic dykes and red sandstone have the power of reducing the oxide of iron and removing it as carbonate.

At Wildenstein, near Büdingen, where the basalt has protruded above the variegated sandstone, there are some portions of the latter that have a columnar structure. Leonhard † saw some columns that were upwards of seven feet long and one inch diameter. The columns have a greyish-white fracture, sometimes with black spots. They are seldom unaltered, and it is only here and there that there are a few fragments of a pale red colour. The unaltered sandstone at a distance from the basalt is, on the contrary, for the most part red coloured, or less frequently streaked or spotted.

The numerous columns of sandstone from Wildenstein in the mineralogical museum, at Bonn, have upon their surfaces an ochre-yellow colour, and are, at some parts, covered with small dendrites, probably originating from deposition of manganese; sometimes they are covered with a thin ochre-yellow crust. There can be no doubt that this hydrated peroxide of iron was deposited from ferruginous water, after the sandstone had assumed its columnar structure. If it were present when the sandstone came in contact with the basalt, the water of hydration must have been driven off by the heat. This coating is also recognisable on the surfaces of fractured columns, though it has here more the appearance of an ochery clay which does not effervesce with acids.

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* English edition, i, 166.

† Loc. cit., ii, 357.

Hydrochloric acid extracted from both the altered and unaltered sandstone some peroxide of iron. At a red heat the former gave off water that had an empyreumatic smell and alkaline reaction, giving also white vapours, with hydrochloric acid. It contained therefore organic substance, which is also indicated by the dark grey colour of the altered and ignited sandstone. These organic remains can, therefore, have been introduced only after the sandstone had been brought in contact with melted basalt, supposing that to have taken place, for the organic substance would, in that case, have been destroyed as in the ignition of the sandstone. There can be no doubt that the same water that deposited the ochery coating upon the sandstone columns also deposited the organic substance they contain.

There can be no question that the columnar structure of the rocks that are brought in contact with basalt, is an evidence of the former high temperature of the basalt. This columnar structure is always the result of contraction, whether this is due, as in the case of clay, to the drying of a wet mass, or whether it is due to the solidification of a melted mass, as in the case of lava. Consequently, the sandstone surrounded by basalt underwent contraction that could have taken place only after previous expansion, of which there is no other assignable cause than heat. It cannot be supposed that a moderate degree of heat, sufficient only to expel the water of the sandstone, would have produced the columnar structure of the latter, for the amount of water is too small to occasion contraction by its expulsion; consequently the heat of the basalt must have been very considerable in order to have produced the columnar structure, as in the case of the masses of stone used in the construction of iron blast furnaces.

I have repeatedly heated to redness fragments of unaltered variegated sandstone, from the vicinity of Wildenstein, without any alteration of the red colour, except, perhaps, increasing its depth; some narrow streaks especially, that in the natural state, were darker red than the remainder of the stone, became dark brick red on ignition. The colouring material in this sandstone, the oxide of iron, could not, therefore, be decomposed or volatilized by the heat of the basalt. Still, the heat was the remote cause of the bleaching of the rock, for by the fissuring of the rock into columnar masses the penetration of water, by which the reduction of oxide of iron was effected, was facilitated.

An unmistakable effect of heat would be presented by a slate that contained hydrated oxide of iron, on its being brought in contact with melted basalt; for there would then be a gradual transition from the red oxide, in contact with the basalt, into brown hydrate; but this indication would, in course of time, be obliterated by the decomposing action of water, more especially since the effects of heat would extend, owing to the slight conductibility of the rock, only a short distance from the line of contact with the basalt.

The result of numerous observations by v. Dechen, shows that the rocks adjoining the melaphyr dykes, in the coal-measures of the Nahe and Saar, are generally quite unaltered. It is only the masses of shale imbedded in the dykes that present some signs of conversion into siliceous slate. But conversion of shale into siliceous slate can result only from the action of water containing silica in solution, and its conversion into clay-stone can only be the result of decomposition, also effected by water. W. Fuchs * also observed that dolomite and limestone traversed by melaphyr, did not present any sensible alteration, and Eichwald † states that the limestone underlying the melaphyr in the Seisser Alps, does not present any sign of alteration. According to Cotta,‡ however, the melaphyr dykes below Predazzo, have rendered the shelly limestone crystalline for a distance of one or two inches.

At the Monzoniberg, in the Fassathal, the line of contact between syenite and granular limestone is very sharp, although the latter does not present any signs of alteration. All the porphyry in this valley presents the same character in this respect.§ In Cawsand Bay, near Plymouth, no signs of any metamorphic action of the porphyry have been recognised in the adjoining slates, unless some slight induration at one or two places can be regarded as the effect of such action. But the slate on the western side of the mass of porphyry, which is nearly half a mile wide, is very much disturbed and contorted.‖ The hyperite that traverses the limestone near Elbingerode, presents a remarkably sharp line of contact with the latter.

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* Die Venetianer Alpen, 1844. p. 14.

† Nouveaux mémoires de la Société impériale des Natural. de Moscou, ix, 154.

‡ Geolog. Briefe aus den Alpen, p. 194.

§ Fuchs und Eichwald, loc. cit.

‖ Lehrb. der Geognosie, i, 773.

Where contact action has really been observed, it is of such a character that there is no possibility of supposing that it has resulted from the influence of heat. Of this kind are the above-mentioned instances of induration and conversion of rocks into siliceous slate. In the mines near Schneeberg, in Saxony, the clay-slate is harder when it is in contact with granite, and is also richer in silica, this character being recognizable to a distance of 800 feet from the line of contact.* Whether this effect is due to the contact with granite or not, the idea of a sublimation of silica into the clay-slate is totally inadmissible.†

Naumann,‡ who took great pains to discover in the rocks, adjoining crystalline masses, alterations that would be evidence of their plutonic origin, was unable to find anything, besides the prismatic structure of some sandstone in contact with basalt, that could be at all ascribed to the influence of heat.

In reference to the fragments of granite, that are not unfrequently imbedded in basalt, he remarks, that sometimes they have not undergone any alteration, and sometimes only a very slight alteration. But such alterations should always be apparent if they resulted from the action of heat, for it is unintelligible that masses of rock imbedded in melted masses, should sometimes present alterations and sometimes none. If, however, these alterations have been effected in the wet way, it is obvious they could have been produced only when the imbedded fragments came into contact with water. Hence, it is intelligible that the fragments of granite in basalt would be found altered or not, according as the penetration of water was or was not possible.

Naumann points out, as a remarkable circumstance, that fragments of granite occur in the scoria of Mont-Denise, near Le-Puy, and the Chuquet-Genesloup, at the foot of the Puy de Dôme, and that in these fragments the felspar is melted, the mica burnt, and whole fragments rendered scoriaceous.

On the other hand, it must be remembered that basaltic scoriæ are among the most fusible kinds of rocks, while the felspar in granite is one of the least fusible, and the mica even still less fusible. When a mixture of such scoria and mica laminæ are exposed to heat sufficient to melt the former perfectly, the latter are merely altered in colour, and do not present any signs of fusion. It may, indeed, be supposed that, in the above instance, the scoriæ were heated far above their melting-point, but such an assumption would not be consistent with the fact observed by Sir H. Davy, that the lava flowing from Vesuvius had a temperature far below that of melting iron. Even this temperature would be insufficient to render granite so liquid that, in cooling, it would have become scoriaceous, for even in a Seftröm's furnace, and with the aid of heated blast, I was unable to melt granite perfectly. Lastly, if we assume that the temperature of the scoriæ, at the time when the fragments of granite were imbedded, was as high or higher than that of an iron smelting furnace, the result of the contact of readily fusible scoriaceous masses with minute portions of granite, would be that the latter would be dissolved, just in the same way that similar fragments of rock are melted in iron furnaces by the action of the fluxes.

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* Breithaupt—Paragenesis, etc., p. 36.

† English edition, i, 34.

‡ Lehrb. der Geogn., i, 773.

It is, therefore, necessary to infer that the alterations observed in the fragments of granite imbedded in scoria must have been exaggerated, and that it does not constitute any proof that they have been produced by the influence of heat.

It has already been shown that melaphyr has not produced any alteration in the rocks with which it is in contact, that could be ascribed to the influence of heat. Nevertheless, Naumann endeavours to ascribe such effects to this rock, as well as to greenstone, diabase, and diorite, though certainly only in rare instances. He refers to localities where shale presents a red colour, as if burnt, or is converted into porcelain jasper, when it is in contact with melaphyr. Similar effects are also said to have been produced by the contact of greenstone and diorite with slate and shale.

The simple examination of the red coloured shale, for the purpose of ascertaining whether this colour was due to the presence of anhydrous or hydrated peroxide of iron, would have decided the question as to whether this colouration was the effect of heat, for the presence of the latter would have been decisive evidence against the action of heat, and would have shown that the colour was due to the ordinary peroxidation of protosilicate of iron in the wet way. But such simple tests are disregarded by geologists, because they have acquired the habit of referring every alteration of rocks to igneous action.

With regard to the conversion of slate into jasper, or any other siliceous substance, I may refer to the remarks that have been already made in connection with this subject, merely remarking here that the notion of silicification by igneous action, is one of the most unreasonable hypotheses ever devised. Naumann, however, is far from being disposed to maintain such an hypothesis, for he remarks that, "actual silicification can probably be effected only in the wet way."*

Naumann states that trachytic rocks sometimes appear to have produced an alteration of the rocks with which they are in contact though less frequently than basaltic rocks. He refers to Poulet Scrope, † who found the trachytic conglomerate at the border of the columnar trachyte in the Island of Ponza, converted, for a distance of from two to thirty feet into a rock resembling pitchstone, and containing numerous crystals of felspar and mica.

The trachytic conglomerate contains from 4 to 4·9 per cent., and pitchstone from 4·9 to 8·5 per cent. water; so that in regarding the above alteration as the result of igneous action, it appears that by the fusion of a hydrated rock, one containing still more water was produced. Trachyte conglomerate is very difficult to melt; and for this reason, that which occurs in the Siebengebirge on the Rhine, is used for the construction of furnaces that have to bear a high temperature. A very intense heat would be requisite for its fusion, and the water would be expelled at the same time instead of more being introduced.

Naumann remarks, that "the effects of contact with porphyry are very rarely recognizable;" and adds, that this is the more remarkable since porphyry is frequently met with in contact with other rocks, and since its pyrogenous nature is confirmed by so many circumstances. He considers that, in this respect, porphyry resembles granite, and believes that some peculiar conditions must have contributed to hinder the action of these rocks upon those with which they come in contact. However, he refers to observations of Davis ‡ and Russeger § which are supposed to indicate such an action, though he regards these instances as doubtful. Lastly, Naumann remarks, that rocks in contact with granite and syenite scarcely ever present characters that can be unmistakably regarded as indicating actual vitrification.

The admission that rocks in contact with porphyry, syenite, and granite do not present indications of the influence of heat at all or but very rarely, is very important in its bearing on the hypothesis that these rocks are of igneous origin; for since they are the least fusible of all known rocks, the temperature of these erupted masses must have been so high, that the effects of heat upon rocks with which they came in contact should be more distinctly marked than in any other case of contact between sedimentary strata and rocks supposed to be of igneous origin, and, like basalt, possessing much lower melting-points. The necessity of assuming the existence of peculiar conditions in order to account for the absence of any indications of the action of heat when granite or porphyry is in contact with other rocks, also throws considerable doubt over the hypothesis of igneous origin. The transmission of heat from one body to another is a necessary consequence of the relative conductibility of both bodies, and is proportionately rapid or slow, but cannot be absolutely prevented. If the heat transmitted to a body is sufficient to produce any effect on it that is permanent after its cooling, this effect would be always recognizable. But if this effect is not apparent, there cannot have been any contact with a heated body. It cannot be supposed that the protrusion of melted masses was accompanied by ascending streams of water, which cooled the melted masses and also the adjoining rock, because then the gradual cooling, which is an indispensable condition of the crystallization of melted masses, could not have taken place.

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* Loc. cit., p. 775.

† Trans. of the Geol. Soc. (2) ii, 205.

‡ Quart. Journ. Geol. Soc., ii, 1846, p. 72.—The rock is called clinkstone, but is, probably, porphyry.

§ Jahrb. für Mineral., 1838, p. 633.

Some of the supposed effects of contact may be ascribed to the more easy penetration of water at the line of contact of two rocks, and the consequent preponderance of alteration at this part. Penetrability and alteration of a rock are inseparable facts; it would be only a perfectly impermeable rock that could be of permanent duration; and, if such a rock existed, there is no reason why its impermeability should ever be altered.

Quite inconsistently with the rare occurrence of chemical alteration where sedimentary rocks are in immediate contact with crystalline rocks, it is assumed also that the metamorphosis of rocks is frequently effected at distances of several thousand feet from the line of contact. Thus, for example, Keilhau states that, in the neighbourhood of Christiania, the alteration of the limestone is recognizable at a distance of from 4000 to 5000 feet from the granite; and that, in the case of the clay-slate, there are numerous instances known where the various phases of metamorphism extend a mile from the line of contact with granite.* This is as much as to say, that, at a distance, an effect is produced that is not apparent at the point of immediate contact.

These assumptions are inconsistent with the known diffusion of heat. They are also inconsistent with the chemical characters of the rocks. Thus at Mettenberg, near Grindelwald, there are beds of limestone scarcely more than an inch thick, and at both sides in contact with gneiss; but neither the grey colour nor the uncrystalline sedimentary character have been at all affected, while distinct fossil belemnites and ammonites occur almost at the line of contact.* In like manner, the alum slate of Christiania in contact with red felspar-porphyry has not undergone any alteration even where layers but a line thick are situated between masses of porphyry on both sides.† With such facts before us, it is impossible reasonably to maintain that gneiss has been produced by igneous metamorphism, or that it has penetrated as a liquid mass between sedimentary strata. It is indeed inconceivable how the hypothesis of igneous metamorphism can have originated or been received.

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* Naumann—Lehrb. der Geographie, i, 781.

The geologists who adopt this view have, however, overlooked the fact that the heat by which it is supposed that crystalline minerals have been produced, must also have produced some effect upon the carbon in the sedimentary strata, and thereby have caused a reduction of the peroxide of iron, while the carbon would be removed as carbonic acid gas. But crystals of felspar are found even in highly carbonaceous roofing-slate.

Studer‡ remarks, that the felspar cystals occurring in sedimentary strata are, at many places, far distant from any crystalline felspathic rock, or that the metamorphic rocks are separated from crystalline rocks, as well as from the high temperature of the interior of the earth, by thick beds of unaltered sedimentary strata, sometimes constituting the upper covering of the latter, at other places, alternating repeatedly with unaltered beds. Thus, for instance, in the Churwalden Valley, in Bündten, white quartz rock, containing bright-coloured laminæ of clay, together with felspar, mica, and quartz crystals in cavities, and gradually passing into gneiss, overlies the fossiliferous grey slate, which is several thousand feet thick. Above the quartz rock there is another bed of grey slate.

To the eastward of Schams, in Bündten, there is a horizontal bed of white marble overlying a bed of flysch§ more than 1000 feet thick. The marble is, again, covered by a conglomerate consisting of marble and quartz cemented together with talc. Together with the hollow quartz pebbles there are large twin crystals of felspar and white laminæ of mica. The more abundant the felspar the more scanty is the limestone; and, lastly, the mass assumes the character of gneiss, in which the green talc and hollow quartz pebbles are the chief constituents. A similar instance is presented at the Glarus mountains, far distant from any crystalline rocks.

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* Studer—Lehrb. der physikal. Geographie und Geologie, ii, 158.

† Ibid., p. 124.

‡ Ibid., pp. 137, 150, et seq.

§ The rock bearing this name is very frequent in the Swiss Alps; it is a calcareous slate, sometimes with thin layers of limestone between the slate.

It has been urged, as an argument against the metamorphosis of rocks in the wet way, that this hypothesis does not account for the fact that masses of unaltered rock are often imbedded in altered rocks.* In reply to this objection, it may be remarked, that the decomposition of a rock takes place only when it is exposed to the undisturbed action of atmospheric agents; while alteration, on the contrary, takes place when the rock is more or less beyond the reach of this action. Basalt, melaphyr, etc., occur, which are quite decomposed at one part, and are almost unaltered at another part. Such a difference is sometimes recognizable in a single fragment, and, what is still more remarkable, even in the same crystal,† as has been already shown in several places. Whether this difference arises from a difference in the character of the rock or crystal at different parts,—whether it arises from one part being more permeable by water than another, or from one part coming in contact with water while the other does not,—it is certain that such differences in the decomposition of rocks would also take place in their alteration. This is the more probable from the fact that, in the alteration of rocks, the substances dissolved in the water permeating them take an essential part; and, therefore, the kind of alteration would depend upon the chemical nature of the substances in the water.

All geologists are unanimous in the opinion that the alteration of rocks by exposure to the atmosphere takes place in the wet way, and I believe I have fully proved that the alteration of rocks otherwise, takes place in the same way. Therefore, dissimilar effects of alteration in adjoining strata cannot be wondered at more than the dissimilar effects of weathering, of adjoining rocks, or even the different parts of a crystal.

Alteration in the wet way is progressive, as is distinctly shown by the phenomena of weathering. Unaltered masses of slate, imbedded in a metamorphic rock, would be still subject to metamorphism after the lapse of thousands of years, if the requisite conditions continued to exist.

At some parts of a metamorphic rock the production of crystalline minerals may take place, and not at another part but little distant. This shows, also, that the metamorphic changes constituted a long and uninterrupted series; so that a great mistake would be made in regarding these alterations as the result of a single process. In a rock permeated by water there is no cessation of the metamorphosis; the products of one phase of alteration are again altered in a subsequent phase, or replaced by new products. Metamorphism by igneous action would, however, cease altogether after the cooling of the rock. Rocks are dissimilar in their conductibility for heat, but not to such an extent that its effects may be produced at one part of a rock, and not at all at another part.

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* German edition, ii, 337.

† Ibid., ii, 338.

Delesse,* who among the French geologists has more especially adopted the views that I hold, and has most convinced himself of the insufficiency of the plutonic hypothesis, made the following interesting experiment. He heated the powder of the following rocks with five times their weight of caustic potash and water, and estimated the amount of substance extracted. He obtained analogous results with solutions of soda and of alkaline carbonates. Since the water permeating rocks contains alkaline silicates, Delesse infers that these substances contribute essentially to the decomposition of rocks, and to the production of pseudomorphs; and he considers that this action must increase with the depth.

		I	II	III	IV	V	VI	VII
Loss by ignition.	Before digestion	1·30	6·00	6·00	4·10	4·00	4·00	....
	After „	0·90	2·89	3·40	0 78	2·90	2·90	....
	Residue after digestion	1·35	5·90	5·75	0·94	3·50	3·05	....
Extracted by alkali.	Water	0·40	3·11	2·60	3·32	1·10	1·43	....
	Lime	Spur	....	1·00	0·40	1·80	0·55	0·40
	Magnesia, alkalies, &c.	0·55	1·82				0·10	1·87
	Alumina	Spur	2·39	3·75	1·16	1·25	1·8	3·78
	Silica	36·00	17·06	19·40	12·23	9 50	19·55	18·30
	Total	36·95	24·38	26·75	17·11	13·65	23·48	24·44
Total loss after igniting the residue		37·85	27·27	30·15	17·89	16·55	26·85	24·44

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* Bull. Geol. (2), ii, 127.

		VIII	IX	X	XI	XII	XIII
Loss by ignition.	Before digestion ...	4·10	8·23	2·98	3·82	—	....
	After " ...	2·70	6·15	2·29	2·00	....	....
	Residue after digestion ...	3·16	7·02	2·77	2·31	....	....
Extracted by Alkali.	Water	1·40	2·68	0·69	1·82	....	....
	Lime	Spur	0·62	0·70	1·08	0·40	0·45
	Magnesia, alkalies, &c.	0·10		4·03		1·00	
	Alumina	1·55	2·10	2·20	2·85	2·60	Spur
	Silica	11·45	7·05	8·50	7·60	4·50	5·35
	Total	14·50	12·45	16·12	13·35	8·50	5·60
Total loss after igniting the residue		17·20	18·00	18·41	15·35	8·50	5·80

I. Spherical trachyte from Glashütte, in Hungary.
II. Trachyte from Heiligenkreuz, in Hungary.
III. Pitchstone from Planitz, in Saxony.
IV. Pitchstone from Meissen.
V. Pitchstone from Santa Natolia, in Sardinia.
VI. Pearlstone from Cape Gates, in Spain.
VII. Obsidian from Lipari.
VIII. Argillaceous eurite from Grumbach, near Dresden.
IX. Palagonite tuff from Iceland.
X. Melaphyr from Belfahy, in the Vosges.
XI. Basalt from Hobschütz, near Bilin.
XII. Vesuvian lava of 1819.
XIII. Quartzose porphyry from the Triebisch valley, near Meissen.

From the above results the following conclusions may be drawn:—

Hydrate of potash never occurs in water, but as Delesse obtained analagous results with solutions of alkaline carbonates, his experiments furnish interesting data for explaining the nature of the metamorphosis effected in rocks by water. It may be objected that the water permeating rocks from above downwards is always cold, and that therefore it could not extract what hot water could. But such an objection would have little weight, since it is rarely, if ever, the case, that, when warm water acts upon inorganic substances, cold water is entirely ineffective. The action of warm water as a general rule is different only in being more intense.

The above table shows that alkaline solutions always extract silica in the greatest proportion from the various rocks. As the greater number of the above-mentioned rocks do not contain quartz, it is evident that the silica thus extracted must originate from the decomposition of silicates. With the exception of I and XIII, alumina is extracted in the largest amount next to silica. There can be no doubt that in the extracted substance this earth was always in the state of silicate; but in II to VIII, it existed together with free silica. This will account for the deposition of hornstone, jasper, and opal, in pearlstone and pitchstone. In the case of the rocks from IX to XII, on the contrary, the alumina bears such a proportion to silica, that the entire quantity of the latter may be regarded as combined with the former as silicate. In IX and X this proportion comes so near to that in orthoclase and in albite, that this silicate would, together with alkaline silicate, yield the material for the production of these kinds of felspar.

It has already been shown* that the minute amount of carbonic acid in meteoric water exercises a decomposing action upon the alkaline silicates in rocks, and that in this way the alkaline carbonates are produced, which exist, together with the alkaline silicates, in the water permeating rocks. When the carbonic acid is consumed, this action ceases. But then the alkaline carbonates taken up by the water produce at lower points in the rocks, the decompositions pointed out by Delesse, that is to say, silicate of alumina is extracted, either with or without free silica. The water in this way obtains the material for the production of most minerals, for silicate of alumina is one of their most constant constituents. This material would be most especially suitable for the production of aluminous zeolites,† which are so frequent in basaltic rocks. For this reason it is particularly interesting that water containing alkaline carbonates extracts from such rocks (IX to XII) silicate of alumina.

The small amount of alkaline earths, especially of lime, in the substance extracted from the above rocks, is owing to the decomposition of silicate of lime and other earthy silicates by alkaline carbonates,‡ and as Delesse digested the rocks with alkaline solutions, only mere traces of free carbonic acid could have been present. If, therefore, carbonate of lime were produced by the decomposition of silicate of lime, very little of this carbonate of lime could have been dissolved, while the alkaline silicates produced would have been entirely dissolved.

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* English edition, i, 2, 3, and 9.

† Ibid., ii, 138.

‡ Ibid., i, 8.

Similar results would take place in rocks. Since, in the upper portions of rocks, the free carbonic acid would be extracted from the meteoric water by the decomposition of the alkaline silicates, there would not be any solvent for the carbonate of lime produced at a lower part of the rock, when the alkaline carbonates acted upon the silicate of lime, and it would consequently remain in the rock.

It must not be forgotten, however, that even in the higher parts of rocks, not only the alkaline silicates, but also silicates of lime would be decomposed by the free carbonic acid of meteoric water.* According to the amount of free carbonic acid, the resulting carbonate of lime would be more or less abstracted from the rock, in solution.

Considering that alkaline silicates are produced not only by the decomposition of silicate of lime by alkaline carbonates, but also by the decomposition of silicate of lime by carbonic acid, it is evident that the water, containing perhaps only a small amount of these alkaline silicates may furnish the material for the production of zeolites, etc.

Since the alkaline carbonates do not decompose silicate of magnesia,† the magnesia which Delesse found was extracted from the rocks, could not be in a state of carbonate, but must have existed in the extracted substance as silicate. In that case it must be inferred that this silicate, which is so sparingly soluble in water,‡ is dissolved by water containing alkaline carbonate.

The above remarks require to be tested by further experiments, in the same direction as those instituted by Delesse.

The following will serve as an example of metamorphic processes. Bicarbonate of lime decomposes various minerals.§ It is present in almost every spring water, and therefore the universality of alteration, in which this substance takes a principal part, may be readily imagined. Considering the great number of displacement pseudomorphs ‖ with the form of calc-spar and arragonite, it may be understood that even water that does not contain lime, would be rendered calcareous by such displacement of carbonate of lime. Water that has in this way become charged with the carbonate of lime acquires the capability of producing new alteration and decomposition. The inexplicable character of the chemical changes in veins, lodes, cavities, etc., when considered from the plutonic point of view, disappears more and more, when attention is directed to the presence of various substances in water, and the capability of their being changed by reaction with the constituents of rock, etc.

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* English edition, ii. 2.

† Ibid., i, 11.

‡ Ibid., ii, 119.

§ Ibid., i, 12. No. 11—15.

‖ Ibid., ii, 43.

Whatever operations go on in veins,—the chief conduits of water,—under the most favourable conditions and become sensibly evident in their result, will also take place in the rocks themselves, in proportion to the degree of their permeability by water. It cannot be too much insisted upon, that it is precisely those substances which are most generally present in water—carbonate of lime and silica—which take so important a share in the processes of metamorphism, because the former is so frequently displaced by other substances, and because the latter so often displaces other substances.*

I have chosen carbonate of lime and silica to illustrate this fact, because they are such constant constituents of spring water. Considering that it also contains alkaline carbonates and silicates, etc., sometimes in considerable amount, it will be evident that the number of possible alterations arising from the reaction of those substances with the constituents of rocks is so numerous and varied, that there is no difficulty in considering them quite sufficient to account for the metamorphosis of rocks.

It is quite certain that those geologists are in error who, regarding crystalline rocks as the products of fusion, refuse to admit that these rocks were formerly quite different from what they now are, and have been brought to their present state by a series of metamorphic processes in the wet way.

Considering a rock in which such a series of pseudomorphic changes have taken place, in which partially, at least, one member has been derived from another, we are led to the conception of enormous periods that have elapsed since the origin of the rock. One or more causes must meanwhile have been uninterruptedly active in order to have produced such considerable alterations. The idea of plutonic metamorphosis extending over such a length of time is out of the question. Even supposing the rock existed at a depth where there was a constant red heat, however long it might remain there, the hydration, for instance of andalusite so as to convert it into steatite, would be quite impossible under such conditions. But where the introduction by water is an essential feature of metamorphic processes, it seems more simple, as this liquid is in perpetual circulation and a constant cause, to regard its action under ordinary circumstances as sufficient to account for the observed phenomena.

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* English edition, ii, 466.

Not unfrequently, it may be seen that during alteration of rocks at the same place, the stratification may be partly preserved, partly obliterated. Thus, near Tarnowitz, in Silesia, the dolomite is stratified at the lower and upper parts, but not in the intermediate part of the bed. The felspathic porpyhry, near Lenne,* consisting of altered strata of the transition series has at some parts, schistose structure, and at others is massive. The frequent instances of the silicification of rocks, adjoining veins, likewise illustrate the obliteration of the former texture. If, therefore, there are reasons for considering that a massive rock has originated from a stratified rock, the absence of stratification is not evidence against this opinion.

Sometimes several different rocks occur together, apparently originating from the metamorphosis of the same sedimentary stratum. In such instances it may be doubtful whether two of these rocks, A and B, are the immediate products of the sedimentary rock, or whether one of these may not have resulted from the metamorphism of the other. If the situation of the metamorphic and sedimentary rocks indicates that A has originated from B, instead of the reverse, while the kind of alteration indicated by the pseudomorphs is opposed to this, the opinion that the alteration of the rock has taken a different direction in different parts of the rock, and that A and B are direct products of metamorphism, certainly gains in probability.

* English edition, ii, 163.

CHAPTER XLIX.

SANDSTONE.

Occurrence.—Sandstones are amongst the most frequent of the sedimentary rocks. They are met with in all geological series, from the grauwacke to the tertiary rocks.

Composition.—These rocks consist of quartz granules, bound together by various cementing substances, to a more or less solid mass. The cementing substance is sometimes silica, sometimes carbonate of lime, sometimes peroxide of iron, sometimes hydrated peroxide of iron, sometimes clay, and even iron pyrites. It is obvious that all deposits precipitated from water may become the cementing substance of quartz granules. The particles of quartz in sandstone vary in size, from microscopic particles to such as are the size of peas, and are often angular without any indications of having been abraded. It is also worthy of notice that, as Gerhardt * has pointed out, the quartz granules of many sandstones are more frequently sharp edged than rounded, and consist of perfectly clear quartz. Since this is rarely the case with the quartz of granite or gneiss, it would appear that the quartz granules in the sandstone did not originate from the disintegrated material of those rocks, but from silica in a state of solution. The granules of quartz, examined by Schafhäutl,† have originated in this way, and indeed by organic agency. They are clumpy, angular, partially opaque and dull, as if dusted with flour; partially translucent, with conchoidal fraction; partly transparent and lustrous, and often are coloured red or green, owing to the presence of imbedded infusoria. In some sandstones the amorphous silica is met with as small wedge-shaped splinters, similar to those produced sometimes when gelatinous silica dries upon the sides of a glass vessel. A specimen of marble, from Neubeuern, contained, according to Schafhäutl, 10 per cent. of silica in the state of coarse-grained sand, that had been deposited by corals perhaps, and was so similar to ordinary sand, that it might be supposed many kinds of sand have been produced in a similar manner.

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* Abhandlungen der Berliner Academie, 1816 and 1817, p. 13.

† Jahrb. für Mineral., 1846, p. 648.

In some sandstone rocks, quartz is met with in a crystalline state. Whole beds consist of crystalline quartz granules, and sometimes of perfectly well developed crystals of quartz, as crystals that penetrate each other's faces, but still present traces of crystalline faces. Thus, according to Breithaupt, the quartz granules in the remarkably pure quartz sandstone, near Tharand, in Saxony, are crystalline. Even the loose arenaceous deposits in the brown-coal series sometimes consist entirely of crystalline granules of quartz.

Such sandstone beds may be compared with quartz dykes or veins, with this difference only, that in the latter the siliceous water flowed down the sides of fissures, and in the former case it has flowed along the beds of rocks, or become stagnant upon them. The difference that the quartz in veins is principally amorphous, and crystalline only in the drusy cavities; while, on the contrary, in the above-mentioned beds it is throughout crystalline, may be owing to the circumstance, that in the former case the dripping water deposits the silica rapidly, in consequence of its rapid evaporation, and therefore in an amorphous state; while in the latter case the silica is deposited slowly, and in a crystalline state from large accumulations of water.

Larger masses of quartz, angular fragments or detritus, and gravel, consisting of quartz, siliceous slate, or flint, are bound together by siliceous, ferruginous, slaty or argillaceous cementing substances, forming conglomerates or breccia of different degrees of hardness.

In the thick beds of grauwacke, quartz occurs as angular or rounded granules, and in small fragments, cemented together by a material consisting essentially of clay or silica.

The so-called crystalline sandstones have already been referred to.*

Composition.—The following analyses of sandstones are arranged in the same order as the geological series to which the rock belongs.

Grauwacke sandstone from Unkel, on the Rhine, analysed by C. Schmidt: †—Hydrochloric acid, extracts alumina, peroxide of iron, some oxide of manganese, traces of lime and magnesia, white silica remained. The cementing material is therefore a silicate of those bases.

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* English edition, i, 365.

† Numerous experiments were undertaken by M. Schmidt in my laboratory, with a view of determining the nature of the cementing material in different sandstones. The results of these analyses were published in his dissertation, "De ligamentis nonnullorum ex diversis formationibus lapidum arenaceorum." In the following account of cementing the materials of sandstones these results are given, except where the names of other experimenters are quoted.

Grauwacke-sandstone, from Dottendorf, near Bonn:—Water removed from this a greyish-brown mud, that did not sensibly effervesce with hydrochloric acid, and consisted of ferruginous clay and oxide of manganese. Besides this cementing material there is another, not so easily separable, that effervesced copiously with acids, and consisted chiefly of carbonates of iron, magnesia, and some carbonate of lime, mixed with a highly ferruginous and manganiferous silicate of alumina, together with white laminæ of mica.

Carboniferous sandstone, from Alsey, in Rhenish Bavaria:—Water separated a yellow cementing material, consisting of white felspathic substance. The yellow colour was due to the presence of yellow particles, that soon also disseminated throughout the whole of the sandstone, and originated from a decomposed ferruginous mineral.

Carboniferous sandstone, from Waldenburg:—The cementing material is also a felspathic substance, coloured by oxides of iron and manganese, originating from dark-red particles, disseminated through the sandstone. A specimen of carboniferous sandstone, from Dortmund, consisted of

Silica	88·33
Alumina (ferruginous)	7·55
Lime magnesia, manganese, and carbonaceous substance	4·12
	100·00

The argillaceous cementing material of this sandstone was very abundant.

Carboniferous sandstone from Schlan-Rakonitz, in Bohemia:—The cementing material is, according to Nowicki,* chiefly kaolin. At one part glauconite predominates; at another, the sandstone containing kaolin is converted into an intimate mixture of silica and kaolin, with a few lenticular masses of pure kaolin, about a foot in diameter, imbedded in places.

Sandstone from the old red sandstone series at Beiber in Spessart:—Water removed from the crushed rock a fine powder of a red cementing material, consisting of very ferruginous clay with oxide of manganese and a small quantity of carbonate of lime.

Sandstone from the same series in Moravia:—The cementing material contains, according to A. Reuss,* carbonate of lime—sometimes in considerable amount. It also contains silver-white laminæ of mica, sometimes in large amount, and mostly situated in parallel lines. The rock then assumes a schistose texture. But sometimes there are large laminæ of mica disseminated throughout the entire mass of the rock.

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* Lotos Zeitschrift für Naturwissenschaften iii, 105 and 110.

The variegated sandstones of various localities from the neighbourhood of Scheweinfurt and the Rhone were examined by v. Bibra.† He digested the crushed rock repeatedly in a boiling solution of carbonate of soda. By this means very little silica was extracted. If, as is probable, the silica in the cementing material has partly passed into the insoluble condition, it would be very difficult in this way to ascertain its true composition.

	I	II	III	IV	V	VI	VII	VIII
Silica	0·2	0·1	—	0·3	0·1	0·02	0·6	0·2
Alumina	1·0	0·2	0·5	0·4	0·7	0·30	0·5	0·5
Peroxide of iron	4·7		0·7				0·6	
Lime	0·6	0·1	0·3	0·5	0·6	0·10	0·8	0·3
Magnesia			0·6				0·5	
Water	0·8	0·2	0·9	0·5	0·5	0·40	0·6	0·5
	7·3	0·6	3·0	1·7	1·9	0·82	3·6	1·5
Insoluble	92·5	99·2	96·5	98·1	97·4	99·10	96·0	98·8
Loss	0·2	0·2	0·5	0·2	0·7	0·08	0·4	0·2
	100·0	100·0	100·0	100·0	100·0	100·00	100·0	100·0

I. Sandstone from Rothen Berg, near Karlstadt; dark red coloured, containing a few laminæ of mica. The insoluble portion consisted of rather fine quartz sand.

II. Sandstone from Lohr; red, coarse-grained. The insoluble portion consists of coarse, slightly-rounded quartz sand.

III. Sandstone from Klingenberg; dark yellow and fine-grained. The insoluble portion consists of pure white and very small granules of quartz.

IV. Sandstone from Herrenthal; slightly reddish and fine-grained. The insoluble portion consists of fine quartz sand, perfectly white.

V. Sandstone from Ashbach (Rhone); dark red and fine-grained. The insoluble portion consists of fine quartz sand, of a slight reddish colour.

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* Dritter Jahresbericht über den Werner-Verein, 1853, p. 16.

† Journ. für practische Chemie. xxvi, 23.

VI. Sandstone from Oschach (Rhone); whitish, rather coarse-grained. The insoluble portion consists of white, imperfectly rounded quartz sand of unequal size.

VII. Sandstone from Uerspringen, near Fladungen (Rhone); white and fine-grained. The insoluble portion consists of fine, white, perfectly rounded quartz sand of unequal size.

The density of these sandstones varied from 2·397 to 2·618.

The very small quantity of silica extracted from these sandstones does not appear to justify the opinion that the cementing material consisted of silicates only. It is not mentioned by v. Bibra whether these sandstones effervesced with acids; but, if the lime and magnesia were not combined with carbonic acid, they must have in the state of silicate.

The quartz granules remaining from the sandstones II, VI, and VIII, were little or not at all rounded, while those from the sandstone VII were perfectly rounded. It is not improbable that the former originated from quartz sand cemented together with silica that was precipitated chemically, and afterwards converted into the insoluble condition.

The quartz granules in the variegated sandstone near Saalfeld, are generally rounded, though they sometimes present smooth and brilliant crystal faces. There were also a very few small decayed granules of felspar, generally rounded, but sometimes presenting crystal faces and cleavage. The cementing material also consisted of decomposed felspar, sometimes in small quantity, sometimes so abundant, that the sand originating from this sandstone is with difficulty permeable by water.*

The cementing substance of the coarsely-powdered variegated sandstone of Oppenheim on the Rhine was separated, as a fine powder, by washing with water, and found to have the following composition:—

Silica	76·86
Alumina	14·95
Protoxide of iron	4·99
Lime	3·20
	100·00

It is, therefore, a very siliceous clay.

Variegated sandstone, from Culmbach in Bavaria, was softened by immersion in water, became friable, and a tolerably large amount of finely divided substance could be washed out, consisting of clay very rich in hydrated peroxide of iron. Variegated sandstone, from Heidelberg, presented much the same character. Besides clay, it contained also gypsum, which appears to be an essential constituent of the cementing material.

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* R. Richter.—Gäa von Saalfeld, 1853, p. 13.

From the results of these experiments, it appears not improbable that clay was the cementing material of the variegated sandstones examined by Bibra.

In the valleys of the Odenwald and Black Forest, which are cut through variegated sandstone, there is a fat, reddish-brown clay soil, which supports a luxuriant vegetation. It is the cementing material of the sandstone that has been washed down from the heights. The rain-water is very turbid, and deposits the suspended substances where it stagnates or flows slowly. The pools, also, in the stone-quarries, contain very turbid, reddish-coloured water; and, in some instances, I have found fissures in the sandstone quite filled with deposit from this muddy water. All these facts show that the argillaceous cementing material of the variegated sandstone is very readily washed away by rain-water. Even some of the springs in this locality furnish only turbid water during rainy weather.

Ewald* found that between Wendelstein and Schwarzenbach, at the junction of the main Danube canal, the sandstone of the keuper series, consisting almost entirely of loosely-bound, coarse quartz granules in its upper bed, takes up a calcareous clayey cementing material, which becomes more abundant towards the surface, and, lastly, preponderates so that it is mixed with only a few quartz granules. At the same time, at this level, the belemnites of the lias occur, which correspond with those in the directly overlying beds of marl perfectly free from quartz. Therefore, the keuper sandstone passes so gradually into the lias strata, that there is no definite line of demarcation between the two series of rocks.

The cementing material of the sandstone of the jurassic series consists, according to Zeuschner,† of the carbonates of lime, magnesia, protoxide of iron, and of clay. A sandstone from Poronin, in the Carpathians, has the following composition:—

White quartz granules and clay	70·23
Carbonate of lime	18·33
„ magnesia	2·60
„ iron	9·77
	100·93‡

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* Zeitschrift der deutschen geolog. Gesellsch. iv, 609.

† Jahrb. für Mineral., 1843, p. 165.

‡ This excess originates from a typographical or clerical error.

Four other specimens of sandstone, from the Carpathians, from Obczyna, near Trieste, from Monte di Repaldo, near Florence, and from Kastropoulo, in the Crimea, contained almost the same cementing material. Zeuschner is of opinion that this is also the case with the sandstone beds of the Carpathians, which contain chalk fossils.

According to Schafhäutl* the sandstone of the jurassic series, in the Bavarian Alps, consist of irregular polyhedric quartz granules, mixed with only a few rounded granules. Some of these granules are coloured reddish brown, or yellowish, by oxide of iron, and among the brown coloured mass there are granules of true argillaceous iron ore. The whole is cemented together with ferruginous clay and carbonate of lime. The bright red particles remaining after the rock has been acted on with cold hydrochloric acid consist of remains of *gallionella ferruginea*, to the agency of which these deposits of argillaceous carbonate of iron owe their origin. In the greenish particles of this sandstone these granules are not found, and the quartz granules are cemented together with carbonate of lime and clay, coloured green with protosilicate of iron.

The following analyses of quader sandstone were made by Reichel:—†

	I.	II.	III.	IV.
Silica (combined)	0·916	0·955	0·020	0·370
Alumina	0·076	0·150	0·180	0·080
Peroxide of iron	0·435	0·374	0·500	0·180
Oxide of manganese ...	0·026	0·016	0·016	—
Lime	0·016	0·010	Spur	—
Magnesia	Spur	0·002	—	0·200
Potash	0·005	0·019	—	—
Soda	0·008	0·024	—	—
Hydrochloric acid	0·001	0·003	Spur	Spur
Ulmic acid	0·016	0·066	Spur	Spur
Bituminous resin	0·020	0·032		
Carbon and Sulphur	Spur	Spur	—	—
Water	0·831	0·850	0·500	0·550
Quartz sand....	97·650	97·499	98·784	98·620
	100·900	100·000	100·000	100 000
Soluble cementing material	2·35	2·5	1·216	1·38

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* Loc. cit. 1846, p. 56.

† Die Basalte und Säulenförmigen Sandsteine der Zittauer Gegend, 1852, p. 22.

I. Sandstone from the "weissen Wand," in the neighbourhood of Johnsdorf, in Saxony. It is fissured into columns from three to ten, and rarely twelve or fourteen feet long, and from two to twelve inches thick; occurring in the neighbourhood of a basaltic cone.

II. Sandstone from the Orgelpfeifen, not far distant from the last-named place. It is also in small columnar masses, from two to three, and more rarely four inches thick.

III. Brownish yellow sandstone from the banks of the Elbe, in Saxony.

IV. White sandstone from the same locality.

Reichel is of opinion that the larger amount of cementing material in the sandstones corresponding to I and II, than in those corresponding to III and IV, originates from basalt, from which it has been transferred to the sandstone by water. In that represented by III certainly but a small quantity of silica was extracted. Probably the cementing material might be washed out of this sandstone.

According to Schmidt the cementing material of the quader sandstone at Tillendorf, near Bunzlau, when washed out with water, consists of:—

Silica	49·32
Alumina	38·54
Lime	0·58
Water	12·03
	100·47

It is therefore kaolin. The cementing material washed out of a quader sandstone at Gröditzberg, in Silesia, likewise consisted of clay, but was slightly coloured with hydrated peroxide of iron, and contained some sulphate of lime, to which the greater hardness of this sandstone, as compared with the previous ones, is probably owing.

These results show that the cementing material of the sandstones examined by Reichel was a very ferruginous clay.

The following analyses of green sand and the rocks allied to it were made by von der Marck:—*

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* Verhandlungen des naturhistorischen Vereins der preussischen Rheinlande und Westphalen, Jahrgang, xii, 263.

Green sand near the Buke station, on the Westphalian railway—

Silica	81·23
Alumina	10·07
Magnetic oxide of iron	4·99
Oxide of manganese	trace
Lime	0·55
Magnesia	0·54
Potash	0·04
Water	3·29
	100·71

Glauconite occurs in detached granules.

Undoubtedly a part of the silica is combined with the bases; so that the cementing material is a highly ferruginous clay, that might be washed out by water.

In most kinds of green sand, however, the cementing material consists of carbonates. These rocks are therefore mixtures of mechanical deposits, with others produced by chemical action or by organic agency.

Green sand from the second bed in the first cutting on the railway between Dortmund and Witten—

Carbonate of lime	40·15
„ magnesia	1·70
Phosphate of lime	0·44
Alumina and peroxide of iron	1·98
Clay, quartz-sand, glauconite	55·73
	100·00

Green sand from the third bed at Buderich, near Werl—

Carbonate of lime	19·7	Cementing material	25·2
„ magnesia	0·4		
Phosphate of lime	2·6		
Alumina	1·6		
Peroxide of iron	0·9		
Silica	19·3	Green granules; glauconite?	33·1
Alumina	3·3		
Protoxide of iron	6·2		
Magnesia	1·1		
Potash	1·1		
Water	2·1		
Quartz	41·0	....	41·0
			99·3

Green sand from the third bed at Lohne, near Werl—

Carbonate of lime	39·50	Soluble in hydrochloric acid.	61·14
„ magnesia	7·23		
Carbonate of iron	7·54		
Phosphate of lime	3·90		
Alumina	2·12		
Peroxide of iron	0·82		
Potash	0·03		
Silica	36·65	insoluble	37·56
Alumina	0·91		
Water	0·62		0·62
			99·32

Connected with these sandstones are the marl sandstone, the beds of the planer chalk-marl, and chalk series. I shall arrange these according to the increase in the amount of carbonates, giving only the total amount of those constituents, as well as that of the substance insoluble in hydrochloric acid. Among the carbonates, the carbonate of lime always preponderates considerably; carbonates of magnesia and iron are present only in very small amount. The portion insoluble in hydrochloric acid consists principally of quartz, with minute quantities of silicates. Those represented by Nos. 17, 18, and 19 appear to consist entirely of silicates.

		Carbonate.	Portion insoluble in hydrochloric acid.
1	Marley sandstone, near Datteln	21·62	77·09
2	The same	25·49	73·86
3	From Jutsum	35·12	64·24
4	Sandstone from Selm and Netteberg	38·5	61·5
5	Pläner sandstone from Barop, near Dortmund	46·23	53·62
6	Sandstone from Cappenberg	55·60	43·76
7	Chalkmarl from Drensteinfurth	55·76	43·77
8	Sandstone from Dülmen	59·39	40·19
9	Pläner Sandstone from the mine, "Freie Vogel" near Hörde	63·46	35·99
10	„ „ from Attenbecken	67·72	31·15
11	„ „ from Hörde	67·88	32·42
12	„ „ from the Buschmühle, near Brüninghausen	69·59	30·88
13	Sandstone from Coësfeld	73·27	26·51
14	Sandymarl, near Cappenberg	84·20	15·20
15	Chalkmarl, from Herrensteinberg, near Hamm	84·30	14·90
16	Pläner sandstone, from Tecklenburg	93·58	6·42
17	Slab-shaped cretaceous limestone, from Ennigertok, near Beckum	95·39	4·90
18	Hard white chalk, from Graes, near Ahaus	95·60	4·40
19	„ „ from the neighbourhood of Ahaus	96·86	2·14

With the exception of the sandstone represented by No. 4, which is very compact, the other sandstones, 1 to 7, containing most insoluble substances, are soft and friable; indeed, that represented by No. 5 soon falls to powder by exposure to the air. The rocks corresponding to 9, 12, 14, 16, 17, 18, 19, containing the largest amount of carbonates, are the hardest and most compact. Those corresponding to 13 and 15 are not very hard, and are less compact; that corresponding to 11 is very soft, and soon falls to powder in the air. In general, it appears that the compactness increases with the amount of carbonate of lime, and decreases as the amount of quartz and glauconite granules increases. The exception in the case of the rock represented by 4 arises from the circumstance that in this sandstone the granules of quartz are imbedded in a matrix of crystalline carbonate of lime. Near to this rock there are others, in which the quartz granules are cemented together, partly by iron pyrites, hydrated peroxide of iron, and peroxide of iron. The iron pyrites is in some places so abundant that it is worked.

The cementing material of the upper cretaceous sandstones in Moravia, which are fine-grained, and are divided into regular slabs, lying either horizontal or but slightly inclined, is, according to Reuss,* carbonate of lime. The amount of this substance is inversely proportionate to that of glauconite granules; the smaller the number and size of these granules, the more carbonate of lime preponderates in the state of fine-grained calc-spar, veins of which also generally traverse the rock. Sometimes the rock passes into a fine-grained limestone, which does not contain any granules of glauconite, or only very few small detached particles. Where these granules preponderate, the rock is less compact, and gradually passes into a loose green sand. Sometimes patches of green sand are situated in the midst of the calcareous mass, or it is interposed in thin layers between beds of the latter rock.

The planer-sandstone of Moravia contains a constant amount of carbonate of lime. The higher the place of the strata in the series, the more does the arenaceous character diminish; the rock gradually passes into the very frequent compact sandy chalk-marl, that constitutes the chief mass of the planer series. This marl occurs, however, in manifold varieties, according as it contains, in preponderating amount, carbonate of lime, argillaceous substances, or glauconite granules. Very fine laminæ of mica form a constant, although very subordinate constituent. Highly calcareous concretions imbedded in the planer rocks, and blended with them, are very frequent. They resemble a compact, very fine-grained, sometimes almost compact limestone, in which laminæ of mica are rarely imbedded, and still more rarely detached green granules. The carbonate of lime from the surrounding rocks has been concentrated in these concretionary masses. Less frequently, but in some places very abundantly, patches of hornstone occur in the planer rocks. At one place the beds of planer rock, from one to two feet thick, are traversed by numerous layers of a milk-white opaline rock, from half an inch to three inches thick, and parallel with the strata, and also by layers of flinty hornstone, six inches thick. At other places transparent granules of quartz are cemented together with an opaque, amorphous, siliceous substance, with numerous small holes. Isolated nests of pitch coal, not unfrequently containing nodules of iron pyrites, often converted into brown hæmatite, are also met with in the planer rocks.

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* Loc. cit., p. 50 et seq.

In the underlying quader sandstone beds in Moravia, the small granules of quartz are cemented together with a scanty, clayey, siliceous material. Sometimes, this is so scanty that the rock soon crumbles to a loose sand. Generally, the quartz granules are distinctly rounded, but sometimes they have an irregular, uneven, rough, and even granular surface, without any signs of rounding. Only in one sandstone did Reuss find detached fragments of highly decayed felspar. Some fine-grained sandstones contain numerous imbedded, silver-white laminæ of mica, sometimes of large size —very minute, detached laminæ of mica are not unfrequent. The manifold varieties of colour, in the lower beds of quader sandstone are due to oxide of iron. These beds contain numerous interposed layers, chiefly of clay and shale. The carbonaceous substances to which the grey shales owe their colour are, in some places, so abundant that they form not only detached nests of true coal, but even seams of tolerable thickness. This brown coal contains from 15·5 to 50 per cent. of ash. It contains brilliant granules of a resin, perfectly similar to amber, and nodules of iron pyrites.

This valuable description of the sandstones in the most recent of the secondary series of rocks in Moravia, shows that the conditions are, in general, the same as in Westphalia. If it were combined with chemical analyses of the different sandstones, they would, without doubt, present as many different combinations of carbonates, quartz, and silicates as are indicated by the chemical investigations of the Westphalian sandstones, by von der Marck.

According to Schmidt, the cementing material of the green sand, near Essen, consists of a little carbonate of lime and finely divided green particles (glauconite). It may be washed out with water, by which means the rock crumbles to powder. In this green sand also dark green glauconite granules are associated with quartz granules. It is worthy of notice, that the water solution when evaporated nearly to dryness, is distinctly alkaline, and contains both potash and soda. These alkalies, probably, originate from decomposed glauconite.

The above investigations show that clay is the cementing material of the quader sandstone, and that carbonates, with minute portions of silicates constitute the cementing material of the green sand and the rocks allied to it.

Tertiary Sandstone.—According to Strickland,* in beds of tertiary sandstone, occurring in the Isle of Man, there are very frequently hard, and often sonorous concretions of quartz sand, cemented with carbonate of lime. According to Schafhäutl,† the cementing material of some molasse sandstones, in the Bavarian Alps, consists of carbonate of lime, together with clay, containing potash; in others it consists of several carbonates, as shown by the following analyses:—

Silica	27·85	74·75	67·60	59·4
Carbonate of lime	2·00	20·59	13·14	30·3
,, iron	56·11	3·11	10·21	9·2
,, manganese	11·48		—	—
Alumina	1·23	1·51	—	—
Bitumen	0·95	—	9·05	1·1
	99·62	99·96	100·00	100·0

The coarse-grained limestones, containing much carbonate of iron, disintegrate very rapidly, the protoxide of iron being converted into hydrated peroxide, while the carbonate of lime is separated by water. But there are sandstones without calcareous cementing material.

According to Zeuschner,‡ the cementing material of the fucoidal sandstone consists of carbonate of lime, carbonate of iron, with a little carbonate of magnesia (8·75 per cent.). Schafhäutl, on the contrary, found no magnesia in the tertiary sandstones examined by him.

Schmidt found that the cementing material of the green molasse sandstone consisted only of carbonate of lime, intimately mixed with small dark green particles of glauconite.

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* L'Institut, 1843, No. 483, p. 108

† Loc. cit., p. 661 et seq.

‡ Jahrbuch für Mineral., etc., 1843, p. 166.

The cementing material of the sandstone of Fontainebleau, a calc-spar impregnated with quartz sand, consists, according to the same authority, of 90 per cent. hydrated silica, 3·7 gypsum, and of lime, together with traces of alumina, oxides of iron and manganese, and magnesia. This cementing material amounts to 7·3 per cent. of the sandstone. It does not crumble in water.

The brown-coal sandstone of Quegstein, in the Siebengebirge, often contains large rounded fragments of quartz. When acted upon by hot caustic potash the cementing material is dissolved and numerous small splinters of quartz remain.* The solution contained much silica, some alumina, a considerable amount of lime and some magnesia. Another variety, with large fragments of quartz, when digested with caustic alkali, was so much acted upon within half an hour, that the imbedded fragments of quartz, siliceous slate, and grauwacke projected distinctly, and some of them could be picked out. After longer digestion the rock crumbled down completely. The substance extracted contained the same bases as that from the above sandstone. After acting upon the residue with sulphuric acid, there remained a small quantity of a very fine white quartz sand, which was therefore mixed with the quartz granules.

At Klein Augesd, near Teplitz, Breithaupt* describes the occurence of a bed four to six inches thick, immediately overlying the brown coal, and consisting of a conglomerate of quartz pebbles cemented together with iron pyrites. This iron pyrites was undoubtedly produced on the spot. The hydrated oxide of iron, which is the cementing material of many sandstones, may, in some instances, have originated from the decomposition of iron pyrites.

Almost all the sandstones examined by Schmidt, became somewhat soft in water, and when small fragments were immersed for a long time, might be broken down between the fingers, more or less easily. Even some with siliceous cementing material, as for instance, the brown-coal sandstone of Quegstein, seemed to become somewhat friable, especially when the cementing material was decayed. Small pieces of the Fontainebleau sandstone, containing but little cementing material might, when immersed for a long time in water, be more easily crumbled at the edges and corners than at other parts, a result that might be connected with the presence of gypsum.

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* Angular granules of quartz are not unfrequent in sand and sandstone. Thus Richter—Loc. cit. p. 14—washed the sand out of marl and slate-clay, the remarkably small fragments of which were tolerably angular, while a few larger granules were completely rounded. At one place these granules were cemented to a sandstone.

† Breithaupt mentions the artificial formation of sandstone in a heap of mine refuse near Freiberg. After heaping up a quantity of fine washed sand, the iron pyrites it contained was decomposed, and the resulting hydrated oxide of iron had, during thirty-five years, cemented the quartz sand together, forming a sandstone, fragments of which could not be distinguished from any natural ferruginous sandstone. In the same way a vein of brown hæmatite was formed in the fissures of washed mud that had dried. Paragenesis, pp. 23 and 47.

Among the older sandstone strata of the transition, carboniferous, and old red sandstone series, there are so few investigations, that nothing can be said with regard to the general nature of their cementing materials. The examinations that have been made show that the principal cementing materials are clay or decomposed felspar. Where these sandstone strata underlie limestone, the cementing material may be, in part, carbonate of lime washed out of those beds. Although clay, or silicates, appear to be the most frequent cementing materials, of the variegated and quader sandstones, it may happen that where shelly limestone overlies the former, it may consist of carbonate of lime. In the oolitic series, where sandstone beds are generally covered by limestone, the presence of carbonates as cementing material, is very characteristic. But it may be that the carbonates in sandstones, do not always originate from the overlying limestone strata; for, as will be shown presently,* the cementing material of the sand may be furnished from sea-water, by the deposition of lime through organic agency. So, likewise, some siliceous cementing materials may originate from siliceous infusoria. Sometimes the cementing material consists of several substances, as in the sandstones of the jurassic series of carbonates and clay.

Where sand has not been bound together by a cementing material, as in the lower silurian strata of Western Russia, sandstone, of course, could not be formed.

From the foregoing data, we may be justified in concluding that the cementing material of sandstones has, in some instances, been supplied in solution by water, and sometimes it has originated from the decomposition of substances mixed with the sandstone. The cementing materials, consisting of carbonates, were certainly supplied in a state of solution in water. This is probable, also, in the case of some cementing materials, consisting only of silicates, or of silica, with small admixtures of basic substances. The very small proportion of these cementing materials, in some sandstones, renders it very probable that they have been introduced by means of water, for the water of ordinary springs drying up in sandstone beds, might leave such small quantities of silicates and of silica.

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* See p. 109.

Since granules of felspar are not unfrequently met with in sandstones, there can be no doubt that the argillaceous cementing materials originate mostly from the decomposition of this mineral. The ordinary products of the decomposition of felspar,* silicate of potash and silicate of alumina, would, when carried away by water, cement the granules of sand in immediate proximity to the decomposing felspar. The not unfrequent occurrence of kaolin, and other analogous silicates in drusy cavities, proves the removal of silicates of alumina. When, as in green sand, glauconite occurs instead of felspar, its decomposition would furnish the cementing material. Iron pyrites, which occurs but rarely as a cementing material, has undoubtedly originated from the alteration of substances in the sandstone itself.

Formation.—The foregoing investigations prove that sandstone strata have been formed, not only from quartzose detritus, but, also from siliceous deposits from water. By far the greater number of sandstone strata are of marine origin; but they have also been formed in lakes. The cementing material was, in either case, supplied by the water of the ocean or the lakes. Beds of sand in valleys may also have given rise to the formation of sandstone. Thus, in the sand of the Vienna basin, there are beds of sandstone with calcareous cementing material, that are rarely more than two feet thick. The formation of such sandstone might result from the permeation of sand-beds by water containing bicarbonate of lime in solution.

J. W. Bailey submitted to microscopic examination some specimens of mud and sand from different depths of the ocean in the region of the Gulf Stream. All those specimens obtained from depths of 306 and 540 feet, presented a striking development of *polythalamia,* which were as abundant as in the marl under Charlestown, in South Carolina. The coarse sand from less depths was found to contain, when washed, siliceous infusoria, exceeding in number and variety those from greater depths. The specimens taken from greater depths contained mostly quartz granules, with fragments of felspar and hornblende; the former were sharp cornered, while, in the specimens from inferior depths, they were more rounded, and even smooth.

Ehrenberg * found, in specimens taken from the bottom of the

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* Berliner academische Berichte von 1854, pp. 54, 236; and 1855, p. 173.

Atlantic Ocean, at depths of 10,800, 12,000, and 12,900 feet, numerous organisms that contribute to the formation of rocks. These specimens were calcareous—the calcareous substances being chiefly small shells, and—less frequently—small calc-spar crystals. Some of the specimens were sand, consisting of smooth granules of quartz. The small shells at the bottom of the ocean are not empty, but are often filled with organic substance. Ehrenberg is therefore of opinion, that at the bottom of the sea, at depths of 12,000 feet, there are both living animal and plant organisms. As regards mass, the *polythalamia* preponderate; while, in number and diversity of species, the *polygastria* and *polycystina* preponderate. At small depths, the latter are not abundant, but they increase with the depth. The calcareous substance from the bottom of the ocean presents, in its animal organisms, great resemblance to the chalk, and, in its exterior appearance, is similar to clay; though it is neither chalk nor clay, but biolithic marl consisting of organized calcareous and siliceous shells, with some quartz-sand and finely-divided earthy substance. It is similar to the marl of Cattanisetto, Oran, and Ægina, though it is not the same.

Ehrenberg* found, also, that the glauconitic sands, sandstones, marl, and limestone occurring in various geological series, even among the lower silurian strata, consist of *polythalamia* and fragments of those organisms, with a few fragments of shells, bivalves, and some siliceous morpholites; also silicified shells and casts. These silicified shells and casts consist of green protosilicate of iron that is not doubly refractive, and is therefore in an amorphous-opaline state, like the siliceous shells of *polygastria*. In some instances, there are also fragments and granules of quartz of different origin, that are doubly refractive and variegated. These granules lie in a calcareous cementing material, from which they may be easily detached by means of dilute hydrochloric acid, and are recognizable under the microscope by the aid of 300-fold magnifying power. Ehrenberg found such glauconite granules at several places in the rocks of the tertiary series, in nummulitic limestone, in green sand underlying the zeuglodon limestone, as well as in this rock, in the upper and lower green sand of England, in loose green sand and in compact green sand near Moscow, as well as in the lower silurian green sand near St. Petersburg, in the chalk of Werl in Westphalia, and of Alabama in North America, in the gault, and in neocomien beds. The green earth, or chloritic earth, occurring as nests, on the contrary, appears, by the aid of the microscope, to be entirely inorganic substances.

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* Berichte von 1854, pp. 374 and 384; and 1855, pp. 86 and 172.

These valuable investigations show that, even at the present time, siliceous shells are formed by organic agency at the bottom of the ocean, and, mixing with rounded quartz granules, may furnish the materials for the formation of sandstone containing quartz of both kinds. The presence of calcareous shells at the bottom of the ocean, shows, also, that the calcareous cementing material of sandstone may be formed by organic agency. Ehrenberg speaks of siliceous shells at the bottom of the ocean, which have been formed by the alteration of calcareous shells of *polythalamia;* the carbonate of lime was therefore dissolved by sea-water and replaced by silica.* This agrees with the fact that, as the glauconitic granules increase in green sand, the calcareous shells disappear more or less,—a relation that is also recognizable in the chalk-sandstones of Moravia.† It is not improbable, therefore, that carbonate of lime may be displaced by protosilicate of iron; and that, in consequence of the displacement, a green sand, rich in carbonate of lime, may be converted into one rich in glauconite, while the organic forms are preserved. If, indeed, the carbonate of lime in the sandstones of Moravia is crystalline, then, if this should be displaced by protosilicate of iron, organic forms would not be recognizable, and only green earth would be produced. Nevertheless, fine-grained calc-spar might be formed from calcareous shells, which would seem possible from the occurrence of crystalline coral limestones.

It is obvious that the veins of crystalline limestone intersecting these sandstones may have originated from calcareous shells. But such formation presupposes the existence of fissures in the rocks, and therefore can have taken place only subsequent to the elevation of the rocks above the ocean.

The greatest diversity of composition and formation of sandstone is manifested in the cretaceous series. In the underlying beds, in the quader sandstone, the quartz sand is cemented by silicates, amounting to only 1·216, or 2·5 per cent; carbonates are never present. But that the conditions for the formation of sandstone were not everywhere present, is shown by the extensive deposits of loose sand in Belgium and near Aix-la-Chapelle, the oldest member of the cretaceous series underlying conglomerates, and the deposits of loose sand several hundred feet thick in Westphalia, in the upper beds of this series.

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* English edition, ii, 479, and iii, 14.

† See ante, p. 103.

In the sandstones resembling hornstone, the cementing material appears to be silica, originating, probably, from the decomposition of silicates, such as felspathic detritus, mixed with the quartz sand. During the formation of these and the above-mentioned sandstones, the agency of organisms, which produce calcareous deposits, was not yet prevalent.

This agency began to be exercised, however, in the formation of sandstone, containg calcareous cementing material, with only a small proportion of silicates. Among the analyses of such rocks that have been made, the amount of carbonates is found to be as much as 21·62 per cent. and it soon increases to such an extent that these rocks may be more properly called limestone than sandstone. Here arenaceous limestones gradually pass into true limestone, or into hard, white chalk, which appear only to contain some silicate. The soft chalk also, when dissolved by hydrochloric acid, leaves a residue amounting, according to von Marck,* to from 1·5 to 2·5 per cent. The soft texture of this chalk appears, therefore, not to be the result of perfect purity.

The organic agency of microscopic marine animals appears, however, not to be limited merely to the separation of carbonate of lime from sea-water, but to extend also to the separation of silica for the formation of their shells. The exercise of this agency acquired its highest development in the formation of glauconite. During the formation of the glauconitic rocks the agency of these marine animals was exercised in the simultaneous separation of carbonate of lime and silica. The separation of this latter substance gradually diminished and that of carbonate of lime alone continued, giving rise to the formation of extensive beds of chalk.

There is, therefore, this essential difference between the quader sandstones and the glauconitic sandstones, that the former originated without organic agency, while the latter were chiefly, if not entirely, formed by organic agency, from material dissolved in sea-water.

The alteration of infusorial deposits into compact siliceous rocks has already been treated of.†

Alteration of Sandstone.—Since the quartz granules, the chief constituent of sandstone, are not subject to alteration, we can only look for such phenomena in the accessory constituents and in the cementing materials. Since sandstones are amongst the most porous rocks, they readily admit of the penetration of water, and, consequently, the most diverse kinds of alteration may be expected in them, and still more in the beds of loose sand that are without any cementing material.

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* Loc. cit. Jahrgung, 1853.

† English edition, ii, 491.

The partial reduction of hydrated peroxide of iron in sand, by the action of organic remains has already been treated of.*

In a white arenaceous clay-bed, in the jurassic series of Moravia, Reuss † found innumerable siliceous concretions, sometimes of considerable size. Externally, they consist of the same sand as that in which they are imbedded, but it is coarser grained, and cemented with a siliceous material. The interior is wholly or partially filled with a siliceous mass of different kinds; in the latter case there is a cavity at the centre. These concretions are not unfrequently filled with a watery liquid. Others, which are never hollow, and which are less frequent, consist of a homogeneous—more or less compact—substance, like tripoli, in which a few indistinct organic remains are imbedded. The concretions, resembling hornstone or flint, are most frequent. According to Reuss, they were formed at the same time as the argillaceous sand, or if orginating subsequently, they were formed, like the flints in chalk, at the place where they are found. He considers it very probable that the greater part of these masses are broken or crushed remains of *amorphozoa*, the structure of which has been mostly obliterated by subsequent infiltration.‡ There is a generally recognisable analogy between these hornstones and the cretaceous flints, in the numerous petrifactions they contain. The ammonites are sometimes hollow inside and lined with quartz crystals. The fossils also occur, though rarely, in the abundant iron ore deposits of the jurassic series in Moravia.

There can be no doubt that the siliceous concretions, described by Reuss, do not originate from dissolved quartz granules. In so far as it is probable that the sand beds have furnished the material for their formation, this can only be sought for in the admixture of clay. Since clay frequently contains alkaline silicates, the decomposition of these substances may have furnished the silica. It is, therefore, desirable that analyses of this arenaceous clay should be made, in order to determine the point.

Mica is a very frequent constituent of sandstone in all geological series. In thousands of fragments of variegated sandstone examined by me, in the neighbourhood of Michelstadt, in the Odenwald, I

* English edition, i, 166, and ante, p 1.

† Dritte Jahresberichte über der Werner-Verein, p. 30.

‡ English edition, ii, 466.

found together with a number of white laminæ of mica, a few dark green or black laminæ. Reuss also speaks of silver white mica in the old red sandstone,* as well as in the planer sandstone,† and in the lower quader sandstone.‡ If these laminæ of mica, that are often so numerous, had been deposited at the same time as the quartz sand, it would be remarkable that they are almost all white mica; for there are no rocks that contain only white mica, even those belonging to the granitic group contain black laminæ, mixed with the white laminæ. If, therefore, the laminæ of mica in variegated sandstone had originated from the disintegration of crystalline rocks, black laminæ of mica would not have been so uncommon in it. If they are of subsequent formation the rare occurrence of black laminæ would also be mysterious, since the material for their formation would not have been wanting. The less difficult decomposition of magnesian mica, as well as the possibility of a conversion of it into potash mica, might, in either case, account for the preponderance of the latter.

These sandstones may be easily split into plates of less than a line in thickness, in which case the surfaces are found to be covered with laminæ of mica. Rocks that cannot be split in this way, very rarely contain laminæ of mica. They are more readily split into thin plates, and contain larger proportions of mica the nearer they are to the bottom of the valleys. The capability of being split, and the amount of mica decrease throughout as the height increases. At the top of the hills large masses of sandstone may be broken without finding a single lamina of mica.

Independently of the facts that laminæ of mica so large as those found in the variegated sandstone, cannot be supposed to exist in the ocean from which this rock was deposited, and that if such large laminæ of mica were carried into it, together with the granules of sand, they must have been ground to powder, the above-mentioned occurrence of mica in a sedimentary rock, cannot be reconciled with the opinion that it is of sedimentary origin. If the variegated sandstone were a sedimentary deposit on coasts, originating from the disintegration of rocks containing mica and quartz, the simultaneous origin of the sand and mica might be accounted for.

The opinion that the mica in variegated sandstone has, like the larger laminæ of mica in clay-slate, been formed subsequently, does not admit of much opposition. The almost exclusive occurrence of these laminæ of mica at the cleavage planes, would then

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[*] See ante, p. 96. [†] Ibid., p. 103. [‡] Ibid., p. 104.

be accounted for by the fact that water penetrates along these planes, and, consequently, at these places, alteration of the rocks takes place, or the constituents for the formation of mica are introduced. Large blocks of sandstone that do not admit of being split into plates, are also harder, and more compact, and less moist at the interior, than thin plates. The intermediate layers that separate the sandstone blocks, near Miltenberg, twenty or thirty feet thick, are penetrated throughout with laminæ of mica, and are so soft and moist that they may be crushed in the hand. The circumstance that much more mica is found in the sandstone at the lower points than on that on the heights, corresponds with the fact, that the water penetrating these rocks accumulates there. Consequently, the effects produced by water, must present themselves in a higher degree in the neighbourhood of the valleys than on the heights.

Since particles of felspar are not unfrequently met with in sandstone, and since felspar may be converted into mica,* the mica in sandstones may be a product of such an alteration. This opinion is favoured by the fact, that the laminæ of mica in sandstone are silver-white, like those of the pseudomorphous mica, with the form of felspar.

Moreover, the luxuriant vegetation upon the variegated sandstone, near Michelstadt, proves the presence of potash and other bases in it. The constituents of the ash of the plants are also those of potash mica. Therefore, the direct formation of mica from its constituents in a porous rock, so easily permeable by water as sandstone, is by no means an impossibility.

In the drusy cavities of numerous fragments of quartz crystals occurring in a sandstone near Oberwiesa, in Saxony, Naumann † found crystals of felspar with fluor-spar. Blum states, also, that the sandstone of Chessy, near Lyons, in which copper-ore occurs, contains fine distinct crystals of felspar, three or four lines thick. They are generally characterized by a greenish colour, like amazon stones, and arising from the presence of malachite. This colour is not superficial, but extends throughout the mass. Fragments of these crystals effervesce copiously with acids.‡

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* English edition, ii, 172.

† Erläuterungen zu der geognostischen Charte von Sachsen, p. 25, et seq.

‡ This occurrence of felspar is an important additional proof of the formation of this mineral in the wet way. It is impossible to imagine that felspar, originating by fusion, could be mixed with a carbonate without the carbonic acid being expelled. It is, nevertheless, worthy of notice, that a felspar formed artificially in this way contained oxide of copper, though not in the state of carbonate. See English edition, ii, 164.

These felspar crystals can only be products of infiltration, whether the material for their formation has been derived by water from fragments of felspar, or from the cementing material. The occurrence of the crystals of felspar in the quartz crystals shows that silica was first deposited by water, and then the felspar.

Decomposition.—The quartz granules in sandstone are not any more liable to decomposition than to alteration. But when the cementing material is either decomposed by chemical action, or mechanically removed by water, the rock crumbles into sand.

Sandstones, from which the cementing material may be washed away, become so friable that they may be crushed between the fingers; and at places where meteoric water has access abundantly they are readily disintegrated. This fact accounts for the frequent grotesque forms of the quader sandstone rocks, as, for instance, at Adersbach, in Bohemia, and in Saxon Switzerland, in Lippe Detmold, and at many other places. Wherever there are hollows in these rocks where water can accumulate and penetrate gradually through the rocks, the cementing material is washed away, and the sandstones crumble down. The road from Adersbach is at many places enclosed with boarding fixed against the rock, so as to prevent the road being stopped up by the frequent falls of sand. While passing through this country during rainy weather, I frequently observed the fall of large masses of sand. The resistance afforded to the action of water will depend upon the degree of firmness with which the granules of sand are cemented together. To this circumstance must be ascribed the fact, that in the midst of the quader sandstone rocks large masses have been carried away, and detached steep rocks and pillars, upwards of 100 feet in height, remain. The unequal cementation of the quartz granules may be owing to the hardening of the argillaceous cementing material, at some places, by the deposition of silica from solution. If the clay contains alkalies, and it is seldom that this is not the case, water would extract alkaline silicates from the upper portions of the beds, and deposit them in the cementing material of the underlying beds, rendering them more coherent and durable.

The following analyses illustrate the decomposition of sandstones, with calcareous cementing materials, by the action of carbonic acid:—

	I.	II.
Insoluble residue consisting chiefly of quartz-sand, and carbonaceous substances	58·74	79·14
Carbonate of lime	27·05	7·58
,, magnesia	7·75	0·74
Alumina	5·66	1·63
Peroxide of iron	....	1·90
Loss by ignition	....	9·07
	99·20	100·06

I. Sandstone, near Baku,* in which the springs for collecting naphtha are situated; from a depth of 1 fathom.

II. Decomposed sandstone, from a depth of 5 fathoms.†

Abich‡ considers that the disintegration of this sandstone is caused by carbonic acid, mixed with the combustible gases, accompanying the naphtha. By its action the greater part of the carbonates are extracted.

As, in this instance, carbonic acid evolved from below the surface dissolves the cementing material, so in the case of sandstone containing a calcareous cementing material, and exposed to the influence of meteoric water, the carbonic acid would determine its solution, and the consequent crumbling of the rock to sand.

CHAPTER L.

SEDIMENTARY LIMESTONE.

LIMESTONE occurs in the sedimentary series of all ages, and often in very extensive masses.

Formation.—Carbonate of lime is deposited from the water of springs as calcareous sinter,§ and in caves as stalactites and stalagmites. The deposition is sometimes due to the evaporation of water and separation of carbonic acid; but it may also take place independently of evaporation, even from very dilute solutions, when water containing bicarbonate of lime in solution is brought intimately in contact with atmospheric air.[*]

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* English edition, i, 252.

† Gottfriedt—Mém. de l'Acad. Impér. des Sciences de St. Pétersbourg. Sér 6, vi.

‡ Loc. cit.

§ English edition, i, 146.

Wherever calcareous water is brought into intimate contact with atmospheric air, such deposition may take place. Thus the sulphuretted water of the springs near Tivoli deposits calcareous sinter to a great extent where it falls in cascades,[†] as well as that of the spring near Smyrna.[‡] The same phenomena is presented by the brine at Neusalzwerk.[§]

When drops of calcareous water remain suspended for some time in the air, they present a comparatively large surface for the displacement of the carbonic acid which holds the carbonate of lime in solution, in consequence of which the stalactites in caves and the incrustation upon the faggots at saltworks are produced. Calcareous sinter is deposited similarly in rivers. Near Heilbronn, on the Neckar, the deposit requires to be periodically removed from the bed of the river.[‖] This river, rising in limestone rocks, is especially rich in carbonate of lime; the water containing in 10,000 parts 4·557 carbonate of lime, nearly as much as the solution already referred to;[¶] consequently, a similar deposition of carbonate of lime might be expected. The experiments with Rhine water,[**] containing only 1·379 to 1·356 carbonate of lime, show that, under favourable conditions, such deposition may take place from river water containing even less carbonate of lime.

The experiments already described[††] show that by the deposition of hydrated peroxide of iron, conglomerates may be produced similar to those containing iron utensils, etc., found in the Rhine below Bingen and near Bonn. This would be the case even in the ordinary flow of a river, owing to the continually renewed contact of the water and air. Additional agitation of the river would facilitate the result.

The water of many rivers does not contain free carbonic acid. Thus Peligot[‡‡] states that Seine water contains carbonic acid only in the state of bicarbonates. Poggiale* found the same. Bineau† often found in the water of the Rhone and its tributaries the same relation between the bases and carbonic acid. The formation of calcareous sinter from such water would take place more readily, and in the absence of free carbonic acid the deposit would not be redissolved. Such rivers may also carry suspended carbonate of lime into the sea.‡

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[*] See ante, p. 7.

[†] English edition, i, 151.

[‡] Poggendorf's Annal. Ergänzungsband i, 373; English edition, i, 154.

[§] English edition, i, 146.

[‖] Schübler.—Walchner's Darstellung der geognost. Verhältnisse der Mineralquellen am Schwartzwald, p. 35.

[¶] See ante, p. 7.

[**] Ibid., p. 12.

[††] Ibid., p. 13.

[‡‡] Comptes Rendus, xl, 1121.

The conglomerate in the bed of the Neckar, near Cannstadt, partly supports the bridge there, and is cemented by calcareous sinter.§ On the banks of the Rhine, near Bonn, I have also found small fragments of stone, cemented together with calcareous sinter, consisting of—

Carbonate of lime	97·92	100·00
„ magnesia....	1·57	
Peroxide of iron	0·51	

The deposit in the lake of Constance,‖ containing 30·76 per cent. carbonate of lime, may have partly originated from the displacement of carbonic acid by atmospheric air, since the water of the lake is considerably agitated, especially near the shores. Simony¶ states that the deposits round the Gossau lake consist only of disintegrated limestone.

At many parts of the sea-coast there are deposits of carbonate of lime. On the reef of Florida a limestone is in course of formation from coral fragments, and is partly exposed at low tide. This portion is very compact; that which is permanently covered by the sea is softer. The former was analysed by Horner and Mariner, and the coral from which it is formed was analysed by Sooville. Horsford** ascribes the induration of this limestone to the decomposition of the animal substance. J. D. Dana,†† on the contrary, ascribes the induration of the coralline sand along the coasts, to the deposition of carbonate of lime between the particles in consequence of evaporation. The action of the air would also facilitate this deposition.

Darwin‡‡ found a cretaceous mud in the lagunes of many coral reefs. Dana observed the same thing. This mud hardens chiefly

* Journ. de Pharm. et Chim. (3) xxviii, 321.

† Comptes Rendus, xli, 511.

‡ English edition, i, 123.

§ Ibid., i, 123, 126

‖ Walchner.—Loc. cit., p. 39. See also Breithaupt Paragenesis, etc., p. 47.

¶ Die Seen des Salz-Kammergutes, p. 12.

** Silliman. Amer. Journ. (2), xiv, 245.

†† Ibid., p. 83 and 410.

‡‡ The Structure and Distribution of Coral Reefs, p. 14.

into a compact limestone; the reason of its remaining cretaceous in some instances is not ascertained. Dana found a considerable layer, not distinguishable from white chalk, in the elevated reef of Oahu, which, according to B. Silliman, jun., consists of—

Carbonate of lime	92·800
„ magnesia	2·385
Alumina	0·250
Protoxide of iron	0·543
Silica	0·750
Phosphoric acid fluorine	2·113
Water	1·143
	99·989

The mass does not contain either infusoria, polythalmia, or other organic remains.

If, as is not improbable, this mass consists of corals that have been ground to powder by the action of the sea, the induration of the cretaceous mud would be gradually effected only by the carbonate of lime dissolved in the water. It may be, therefore, that as this goes on, the mass is converted into compact limestone.

L. v. Buch* remarks, that the violent wind prevalent in the Canary Islands during the summer, sweeps fragments of shells, trachyte, and basalt, across the narrow isthmus of Guanarteme, and deposits them on the other side, in dunes 30 or 40 feet high. Behind these dunes the wind does not reach the coast again. The waves constantly agitate the sand, and it is cemented together by the water into a solid mass. This takes place only when the sand is sheltered from the wind.

These facts show that the deposits of limestone forming conglomerates are effected by the action of the atmosphere. The cementation of the fragments requires, however, a period of rest, otherwise the deposit is again broken up. But, although the conditions favourable to the formation of such deposits were recognized by v. Buch, the mode in which it takes place was not evident. The opinion put forward by me,† that this consisted in the evaporation of sea-water, requires to be modified by the fact that atmospheric air displaces carbonic acid. This action would certainly be facilitated by the motion of the waves.

The formation of sandstone on the Sicilian coast, described by De Saussure, Spallazani, and others, may be due to a similar cause, the sand being cemented by ferruginous marl. This sandstone acquires such hardness in the course of thirty years, that it can be used for mill-stones. On some parts of the coast of Asia Minor, Hoff* states that sand and shingle are cemented by a calcareous cement, and in other places thick layers of limestone are formed. Beaufort mentions several instances of a similar kind in other localities, and remarks that the water of the rivers at the mouths of which this phenomenon is observed is highly impregnated with lime. Spallanzani describes conglomerates that are formed near the lighthouse at Messina, and are hard enough to be used for mill-stones. Péron states that in the South Sea Islands sandstone is continually being formed from the sand of the dunes. Nöggerath describes a very hard conglomerate of various detritus, sand, and shells, which are cemented with ferruginous limestone to a very hard mass. When broken, a wrought-iron ring, three inches diameter, was found in it. Some of the iron was corroded from the surface, and had been converted into cementing material. There was also some wood attached to it, converted into hydrated peroxide of iron. This conglomerate was found in the sea, near Ostend, and was similar to those found in the Rhine. Some beds of limestone in tertiary formations, like the Leitha limestone in Moravia, described by Aug. Reuss† as situated on the shallow parts of a former sea-coast, may have been formed in this way. This limestone sometimes contains quartz granules, and is thereby rendered similar to sandstone. It rarely contains fossils, and those that do occur are very indistinct; in the lower beds they are almost absent.

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* Phys. Beschreib. der canar. Inseln. See also English edition, i, 179.

† English edition, i, 178.

In the sea, and especially upon the coasts, the conditions for the deposition of carbonate of lime exist to the greatest extent. There the agitation of the water is much greater than in rivers and lakes. The frothy surf is most intimately mixed with atmospheric air; and, in addition to this, the tides contribute to the renewal of contact between water and air. The influence of the tides upon the formation of sedimentary deposits, pointed out by C. H. Davis,‡ extends also to those produced by chemical action.

Since the carbonate of lime, separated from solution by the displacement of carbonic acid, is not precipitated in the same manner as when carbonic acid is passed through lime-water, but is deposited upon the sides and bottom of the vessel, it may be conjectured that the carbonate of lime separated in this way from river and sea-water would also be deposited at the bottom of the rivers, or of the sea.

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* Geschichte der natürlichen Veränderungen der Erdoberfläche, ii, 256.

† Dritter Jahresbericht über den Werner-Verein, p. 94.

‡ English edition, i, 138.

The following analyses of limestones* from the older geological series show that as regards composition there seems to be but little difference from those of later series, except that the former are generally more impure, and do not contain so much carbonate of lime as the limestones of later date:—

	I.	II.	III.	IV.	V.	VI.	VII.
Carbonate of lime	90·09	39·54	19·51	79·97	63·10	73·34	89·24
„ magnesia ..	1·26	1·85	1·04	0·52	0·80	0·28	0·19
„ manganese ..	..	..	..	..	..	..	0·19
Alumina and sesquioxide of iron	2·30	4·68	1·21	0·82	8·51	1·16	0·07
Phosphoric acid	0·46	0·16	0·14	0·56	0·55	0·44	0·21
Insoluble substance.. ..	5·13	52·27	73·13	17·85	26·98	24·03	8·29
Organic „	..	0·73	3·50	0·56	0·33	0·33	0·77
Water	0·76	0·53	1·47	..	..	0·54	0·22
Loss		0·24					0·82
	100·00	100·00	100·00	100·28	100·27	100·00	100·00

I. Upper silurian Wenlock limestone, from Dudley.

Very fossiliferous. Density, 2·70, at 60° F. The insoluble substance seemed to be Wenlock shale.

II. Lower silurian Bala limestone, from Ysputty Evan, North Wales.

Did not contain any fossils, and the calcareous portion was crystalline.

III. Lower silurian Bala limestone, from Rhiwlas.

Fossiliferous, but very impure. The residue appeared to be clay.

IV. Lower silurian limestone, from Dinover Park, near Llandeilo.

Very fossiliferous, compact, and dark blueish-grey coloured.

V. Cambrian limestone, from Church Stratton, Longmynd.

Blueish-grey coloured, compact, and slightly crystalline.

VI. Cambrian limestone, from Craigmuir, near Inverary.

Compact, but not hard, grey coloured, and separated into laminæ, parallel to the bedding, by plates of white mica. Beds from six inches to several feet thick alternate with clay-shale, and rest upon clay-slate.

VII. White limestone, occurring as veins and irregular masses in hornblende schist, at Krageroe.

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* David Forbes.—Phil. Magazine, 4, xiii, 365.

CHAPTER LI.

CLAY-SLATE, GRAUWACKE, SHALE, ETC.

THESE rocks occur very abundantly, under various forms, in all geological series prior to the new red sandstone. They are all of sedimentary origin, from the finer detrital materials carried down by rivers. They present a general similarity in composition, consisting chiefly of silicates of alumina, iron, and alkalies, mixed with quartz, sand, etc.

	I.	II.	III.	IV.	V.
Silica	62·59	64·58	61·74	67·50	60·03
Alumina	16·88	17·10	19·81	15·89	14·91
Peroxide of iron	8·42	7·43	10·08	5·85	8·94
Lime	0·24	0·16	0·83	2·24	2·08
Magnesia	2·26	2·29	3·03	3·67	4·22
Potash	3·31	2·93	1·95	1·23	3·87
Soda	..	..	1·31	2·11	..
Oxide of Copper	0·13	0·30	..	0.28	..
Carbonate of lime.. ..	1·22	0·53	..	..	..
Water	4·03	4·08	0·93	1·13	5·67
Carbon and loss	0·92	0·60	0·07	..	..
	100·00	100·00	99·75	99·62	99·72

	Analysed by
I. Clay-slate, greyish-black roofing slate, from Bendorf, near Coblentz	Frick.*
II. Clay-slate, greyish-black roofing slate, from Lehesten, in Thuringia	Frick.*
III. Normal clay-slate from the Selkethal Harz	Pierce.†
IV. Clay-slate from Prague	Pleischl.‡
V. Clay-slate from Goslar	Frick.§

The presence of copper in I, II, and IV is remarkable; it would most likely be found in other instances if the liquid from which silica has been separated were treated with sulphuretted hydrogen.

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* Poggend. Annal. xxv, 188.

† Rammelsberg's Handwörterbuch, Suppl. iv, p. 234.

‡ Journ. für prakt. Chem. xxxi, p. 45.

§ Poggend. Annal. xxxv, 188.

The clay-slate II was analysed both in the altered and unaltered state by Suckow.* His analysis of the latter corresponded closely with that by Frick. The analysis of the former showed that the greater part of the lime, magnesia, and potash, together with a small portion of the alumina, had been removed, while the amounts of oxide of iron and silica were increased, probably, only relatively. Rammelsberg remarks, however, with justice, that these analyses do not seem to be correct.

	VI.		VII.		VIII.
Silica	72·51		67·82		64·35
Alumina	12·89		12·98		20·62
Protoxide of iron ..	..		10·55		7·06
Peroxide of iron ..	4·15		..		2·59
Lime	0·60		..		0·10
Magnesia	0·93		0·84		0·81
Potash	4·02		0·57		2·22
Soda	..		1·15		0·20
Water and carbonic acid	4·44	Loss by ignition	7·00	Water and trace of org. subst.	2·05
	99·54		100·91		100·00

Analysed by

VI. Clay-slate from the Morgenröthe mine, near Siegen } Schnabel.†

By hot sulphuric acid all the bases were extracted from this slate.

VII. Clay-slate, associated with iron-spar, from the Friedrich Wilhelm mine, near Siegen } Bischof.

The iron-spar was separated as carefully as possible. The powder, when rubbed in a chalcedony mortar, felt gritty, and, therefore, contained quartz. At some places there was a brassy-coloured film, probably of speiss cobalt.‡

VIII. Clay-slate from near Lüdenscheidt, in Westphalia } Von der Marck.§

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* Die Verwitterung im Mineralreiche, p. 166.

† Communicated by him.

‡ The melted mineral, covered with hydrochloric acid, gave off a smell of chlorine. The solution was red, but the colour afterwards disappeared, and again became perceptible when the residue of evaporation was covered with dilute acid. I have not been able to account for the excess which was observed, although the iron was calculated as protoxide.

§ Op. cit.

	IX.	X.
Silica	59·82	58·85
Alumina	16·19	15·79
Peroxide of iron	8·41	10·84
Lime	0·18	trace
Magnesia	1·87	0·18
Potash	4·19*	3·52
Soda		0·96
Carbonic acid	2·96	..
Loss by ignition	6·38	7·90
	100·00	98·04

Analysed by

IX. Clay-slate adjoining the Silbernaler lode at Clausthal } Kjerulf.

X. Clay-slate from the upper portion of the Silbernaler lode } Bischof.

This lode, consisting of clay-slate, was pointed out to me by Zimmermann. It is not metalliferous at the out-crop, but only at some depth. After the analysis was finished, I observed some microscopic veins, apparently consisting of iron-spar. In one of these veins brown iron ore was distinctly recognizable. Fragments containing such veins were picked out, powdered, and covered with hydrochloric acid, but no effervescence was perceptible until heat was applied. The considerable deficiency in the analysis, probably, originates from carbonic acid that was only partially separated by ignition. In the clay-slate adjoining the lode, the carbonic acid is chiefly combined with protoxide of iron, together with minute portions of lime and magnesia. The presence of iron-spar in the lode, and in the clay-slate adjoining, corresponds with the frequent association of the metalliferous minerals with this ore at this place.

The composition of both clay-slates shows a correspondence that does not admit of any doubt as to their similar origin. The larger amount of iron-spar in the lode has been, probably, conveyed to it by water from the adjoining rock, while the lime and magnesia were for the most part removed in the same way.

The clay-slate of the rock adjoining the lode is a mechanical sediment, and that of the lode itself must have a similar origin. But the deposition of the rock must have been at an end before the lode fissure was formed. If the sediment was fissured before being raised above the ocean, the fissure might be filled with suspended material. But between the deposition of the rock and that of the lode substance, a long interval would have elapsed, during which the composition of the material suspended in the sea remained as constant as is shown by the above analyses. While this deposition was going on in the fissure, a further deposit of the same kind would have taken place on the surface of the rock. But if the rock was fissured after its elevation above the sea, the fissure must have been filled from above or from below. According to the plutonic views the filling would take place from below if the lode material consisted of a crystalline mass. Some geologists would, probably, hold that the fissure was filled from below with a pasty mass; and to account for the similarity of the lode mass and the adjoining rock, it might be assumed that the lower portion of the clay-slate was rendered pasty by the action of water, and forced up by the pressure of steam. It is, however, difficult to suppose that the steam would have exercised only a mechanical action, and not have decomposed the pasty mass. In that case the composition of the lode mass would not resemble so closely that of the adjoining rock, at least the alkalies would have been extracted.

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* Estimated from the deficiency.

I am of opinion that the filling of this fissure was effected by surface water holding in suspension particles of the clay-slate from the vicinity. If the opening of the fissure were only a few inches lower than the surrounding surface of clay-slate, the muddy water would flow into it. At first it may have been very narrow, and afterwards gradually widened, without the successive deposition of suspended material being in any way hindered. If this suspended material was not only mechanically subdivided, but also to some extent chemically decomposed, if the protoxide of iron were partially peroxidized, organic substance might, after the deposition in the fissure, have exercised a deoxidizing influence.

Sauvage examined the clay-slate from the Ardennes, and from northern Asia, by heating it first with concentrated hydrochloric acid, then with sulphuric acid, and extracting from both residues the soluble silica by means of caustic potash. The residue from this operation was generally quartz. He analysed the hydrochloric and sulphuric solutions separately; but, as he himself remarks, this method does not insure any complete separation of the constituents soluble in the respective acids, and, therefore, I have calculated the results as a whole.

Sauvage * found that clay-slate often contains more than one-third its weight of quartz, which is often mixed with small quantities of potash and soda-felspar. He also found that clay-slate contains an anhydrous silicate of alumina, consisting of equal equivalents of its constituents, mixed with small amounts of silicates of magnesia, potash, and soda. This silicate of alumina contains three times as much alumina as orthoclase, and twice as much as oligoclase. Besides these constituents, Sauvage found in clay-slate, chlorite mixed with peroxides of iron and manganese, and an organic substance which gives the rock a grey or blueish-grey colour. All these constituents are intimately mixed and disseminated throughout the mass of the slate. The chlorite exists as an extremely fine powder, penetrating all the other constituents. The silicate of alumina generally exists as shining laminæ, that may be recognized by their reflection when the powdered slate is freed from organic substance and suspended in water.

	XI.	XII.	XIII.	XI A.	XII A.	XIII A.
Silica	67·38	61·03	63·81	41·44	41·91	39·69
Alumina	18·22	24·30	18·41	32·71	36·23	30·68
Peroxide of iron ..	1·02	..	..	1·83	..	..
Protoxide of iron	4·71	4·66	7·36	8·46	6·95	12·27
„ of manganese	0 30	0·09	..	0·54	0·13	..
Lime	..	0·80	1·10	..	1·19	1·83
Magnesia	3·98	1·71	3·96	7·15	2·55	6·60
Potash	2·65	1·88	2·27	4·75	2·80	3·78
Soda	..	0·98	0·98	..	1·46	1·64
Water	and carbon 1·74	4·55	2·11	3·12	6·78	3·51
	100·00	100·00	100·00	100·00	100·00	100·00

XI. Greyish-green slate from Deville.

It contained a little magnetic iron ore and iron pyrites. The former was separated before analysis, by the magnet. The residual quartz contained traces of a mineral containing an alkali, and amounted to 44·3 per cent.

XII. Dark green slate from Monthermé.

This contained a few laminæ of mica. The residual quartz contained a few laminæ of felspar, and amounted to 32·92 per cent.

XIII. Greenish slate from Rimogne.

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* Annales des Mines (4), vii, 411.

By means of the magnet 2·5 per cent. magnetic oxide of iron was separated. It is not stated whether the 40 per cent. of residue was pure quartz.

The first three analyses give the compositions of the slates as a whole, taking the residue as pure quartz, and adding it to the silica. Nos. XI A, XII A, and XIII A, give the compositions of the portions extracted by hydrochloric and sulphuric acids.

The compositions of these three portions present a tolerably close resemblance, which is more apparent when the alumina and peroxide of iron are added together, and the total compared with the silica.

The close correspondence between the more recent analyses of various clay-slates by Frick and Sauvage might lead one to suppose that the oldest analysis of clay-slate, by d'Aubuisson, in which the amount of silica is comparatively small, is incorrect. However, there are other instances of clay-slate with a small amount of silica.

	XIV.	XV.	XVI.
Silica	48·6	50·01	47·08
Alumina	23·5	34·74	36·01
Protoxide of iron	11·3	3·73	4·96
Sesquioxide of manganese	0·5	..	..
Magnesia	1·6	0·87	0·69
Lime	..	..	trace
Potash	} 4·7	7·21	6·27
Soda		0·04	0·37
Loss by ignition	7·6	3·27	5·43
	98·0	99·87	100·81

XIV. Analysis of clay-slate by d'Aubuisson.*

XV and XVI. Clay-slates from the Pferd mine, near Siegen.

These slates constitute the saalband of the iron-spar lode. They have the appearance of roofing-slate, but are not separable into such thin laminæ. No. XVI contains, disseminated through it, fine veins of sphæroiderite, which was carefully separated before analysis. Even this slate, in its natural state, did not contain more than a mere trace of lime. Both slates were free from quartz granules, and probably did not contain any free silica.

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* Traité de géogn, ii, 79.

	XVII.	XVIII.	XIX.	XX.
Silica	55·74	51·83	78·00	72·87
Alumina	15·61	22·22	9·73	13·71
Peroxide of iron	8·22	7·50	..	..
Protoxide of iron	5·82	..	2·68	3·48
Lime	0·50	..	1·12	..
Magnesia	1·39	1·38	2·29	0·61
Potash	6·16	9·11	4·62	5·29
Soda	1·71	1·75	3·11	1·30
Water	4·85	5·56	1·07	3·28
	100·00	99·35	102·62	100·54

XVII. Taunus slate from Nertohal, between Wiesbaden and Platte } List.*

This slate had a reddish violet colour and silky lustre.

XVIII. Sericite from near Naurod. List.*

This is perfectly similar to the crystalline constituent of various kinds of Taunus slate. List is of opinion that Taunus slate is a mixture of this mineral with quartz, in very variable proportions.

XIX. Greenish modification of Taunus slate. List.*

This may be regarded as the normal slate.

XX. Normal Taunus slate. R. Wildenstein.†

F. Sandberger ‡ states that these constituents of Taunus slate are found separately, almost pure, as layers, generally but a few lines thick. In some places albite is mixed with them, but always in small amount. The various modifications of Taunus slate present an unequal crystalline appearance, and all the above minerals are bedded with the normal slate.

The numerous fissures in Taunus slate are filled with quartz.§ The cavities generally contain crystals or crystalline masses of albite. They occur as large fine-grained masses in the quartzose slate at Würzburg, and at the Leichtweishöhle, with disseminated microscopic crystals of magnetic oxide of iron and micaceous iron ore.

Among the zeolites that occur in cavities, is aphrosiderite,‖ together with quartz and albite, and also beads of epidote.

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[*] Jahrb. d. Verein. für Naturkunde im Herz. Nassau, vi, 129.

[†] Ibid., p. 131.

[‡] Ibid., p. 2.

[§] Quartz occurs as colossal masses in the Frauenstein lode, which is 80 feet thick, and in some parts 70 feet high.

[‖] Ueber. d. geol. Verh. von Nassau, p. 97. This mineral is stated by F. Sandberger to occur throughout the whole district of Weilburg, Limburg, Dietz, and also in the neighbourhood of Dillenburg, generally associated with ankerite, or quartz. Op. cit. p. 40.

Semi-opal occurs in the fissures intersecting the stratification of the rock; at some places it is quite soft, and almost always associated with micaceous iron ore and brown iron ore, so that it must be inferred to result from the progressive decomposition of the slate. By long contact with the atmosphere it becomes soft and earthy, and loses its lustre, probably in consequence of decomposition.*

The crystalline character of the Taunus slate is an important proof that the metamorphosis of sedimentary rocks takes place in the wet way. A mineral containing so much alkali as sericite may readily furnish material for the production of albite in the fissures. It would only be requisite that some silica should be introduced, and some peroxide of iron removed. The fissures in the Taunus slate are filled with quartz, and the beds of iron ore, show the product of decomposition. Taunus slate appears to contain a larger amount of alkalies than any other yet analysed, more even than some crystalline rocks, such as trachyte, syenite, granite, etc. The large amount of soda is also noticeable.

Hausmann† describes a compact felspar rock near Osterode, which corresponds with that called adinole by Beudant, and is bedded alternately with siliceous slate. According to Schnedermann its composition is shown under A:—

	A.	B.	C.
Silica	71·60	79·5	69·09
Alumina	14·75	12·2	19·22
Peroxide of iron..	1·41	0·5	..
Protoxide of manganese	trace	..	..
Magnesia	trace	1·1	..
Lime	1·06	..	..
Potash..	0·32	..	..
Soda	10·06	6·0	11·69
	99 20	99·3	100·00

B is Berthier's analysis of adinole from Sahla, in Sweden; and C shows the composition of normal albite. Therefore A and B would seem to be essentially mixtures of albite and quartz. According to Grandjean‡ compact albite occurs at Merkenbach, near Herborn, associated with green siliceous slate.

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* English edition, ii. 461.
† Ueber die Bildung des Harzgebirges, p. 79.
‡ Op. cit. p. 40.

The occurrence of albite in fissures of clay-slate shows very distinctly that it has been formed in the wet way.* Grandjean† states, that it occurs as well developed, but somewhat altered, crystals, in a bed in the grauwacke, near Niederrossbach and Dillenburg.

B.—*Clay-slate, Siliceous-slate, and Grauwacke, containing Carbonates.*

Slates that effervesce copiously with acids occur near Ostwig, Nuttlar, and Antfeld, alternating with black, compact limestone, from half a foot to five feet thick, and traversed by veins of white calc-spar. These strata belong to one of the upper sections of the Devonian system, since they occupy a position above the Eifel limestone, and are covered directly by nodular limestone. These roofing slates alternate, also, with black clay-slates, which are distinguishable from them only in not having that cleavage which is requisite for technical purposes. Similar slates, also traversed by veins of white calc-spar, occur near Howald and Maiworm, on the Bigge, north of Olpe.

		XXI.		
		A.	B.	C.
b.	Silica	45·40	64·51	51·64
	Alumina	9·92	14·10	11·16
	Peroxide of iron	8·35	11·86	10·34
	Lime	trace	trace	15·78
	Magnesia	0·65	0·92	0·90
	Alkalies, Water, and Organic Substances.. ..	9·05	8·61	10·18
a.	Silica	0·49		
	Peroxide of iron, containing alumina	0·84		
	Carbonate of lime	24·99		
	„ magnesia.. ..	0·31		
		100·00	100·00	100·00

XXI. Roofing slate from the Loh mine.

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* English edition, ii. 192.

† Jahrb. des Vereins, etc. p. 40.

		XXII.		
		A.	B.	C.
b.	Silica	38·80	58·91	44·41
	Alumina	9·44	14·33	10·88
	Peroxide of iron	11·71	17·77	16·19
	Lime	Spur	Spur	16·50
	Magnesia	0·39	0·59	0·53
	Alkalies, Water, and Organic Substances.. ..	10·17	8·40	11·49
a.	Silica	0·50		
	Alumina	0·19		
	Peroxide of iron	2·62		
	Carbonate of lime	26·02		
	„ magnesia.. ..	0·16		
		100·00	100·00	1000·00

XXII. Roofing slate from the Ostwig mine.

Neither of these slates present any appearance of particles of carbonate of lime, even when examined with the microscope.

A and A give the exact composition of these slates. In the analyses *a* hydrochloric acid was used; in *b* carbonate of potash was used for decomposing the slate.

B and B give the composition after deducting the carbonates.

C and C give the composition when the bases of the carbonates are added to those of the silicates, on the supposition that the former have originated from decomposition of the latter. Whether this was the case, or whether the carbonates were infiltrated, is uncertain. The composition XXI B is nearly the same as that of the roofing slate at Lehsten, and that of XXII B closely resembles that of clay-slate from Devonshire. Hence the carbonate of lime may have been infiltrated, and this is more probable, since the slate alternates with limestone beds, which most likely yielded the carbonate of lime for the calc-spar veins.

Although the silica extracted by hydrochloric acid may have been combined with lime, as the residue of silicate of lime, it is less probable that the carbonate of lime in this slate originated from silicates of lime.

The opinion that the clay-slate mass was deposited from the ocean simultaneously with the carbonate of lime is, perhaps, the most probable, more especially as the limestone alternates with the slate, for where chemical and mechanical deposition went on together, it is improbable that one or the other would be suddenly discontinued.

	XXIII.	XXIII A.	XXIV.	XXIV A.
Silica	75·73	87·05	78·6	82·80
Alumina	5·57	6·40	9·1	9·58
Peroxide of iron	..	4·75	..	4·35
Lime	0·16	0·19	..	..
Magnesia	0·32	0·37	0·5	0·53
Potash	0·46	0·53	..	..
Soda	0·30	0·34	..	..
Carbonate of lime	9·40	..	2·5	..
„ magnesia	2·50	..	0·7	..
„ iron	6·00	..	6·0	..
Loss by ignition (trace of carbon) ..	0·32	0·37	2·6	2·74
	100·76	100·00	100·0	100·00

XXIII. Compact blueish-gray grauwacke, from a quarry on the road to Volme } von der Marck.*

By weathering this rock passes into a loose greyish-brown sandstone.

XXIV. Black siliceous slate, detrital masses from the Lenne } von der Marck.*

XXIII A and XXIV A. The same after deducting the carbonates.

The reasons given by von der Marck for inferring the presence of carbonate of iron in these slates do not seem to me satisfactory, and the total absence of silicates of iron is inconsistent with all other analyses of such rocks.

	XXV.	XXV A.	XXVI.	XXVI A.
Silica	54·32	66·64	84·05	91·82
Alumina (trace of iron)	21·81	26·76	5·68	6·21
Magnesia	0·50	0·61	0·26	0·28
Potash..	3·75	4·60	1·29	1·41
Soda	0·34	0·42	0·27	0·28
Carbonate of lime	8·98	..	1·02	..
„ magnesia	2·12	..	0·65	..
„ iron	7·57	..	7·01	..
Carbon	0·79	0·97	..	..
	100·18	101·00	100·23	100·00

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* Analysen von Gebirgsarten aus dem Westphal. Uebergangsgeb. Verhandl. des Naturhist. Vereins der Preuss. Rheinlande und Westphalens. Jahgr. viii, p. 56.

XXV. Clay-slate constituting the underlying bed of the metalliferous deposits at Ramsbeck, in Westphalia, consisting of galena and zinc blende, with some iron and copper pyrites	Amelung.*

This clay-slate contains at parts very minute crystals of iron pyrites.

XXVI. Grauwacke, containing small white laminæ of mica, and constituting the overlying bed of the metalliferous bed.

XXV A and XXVI A. The same after deducting the carbonates.

This metalliferous deposit consists of a system of parallel beds, both the clay-slate and the grauwacke containing ores.

In four specimens of limestone from the Westphalian transition rocks, Von der Marck† found the quantity of substance insoluble in acids varied from 28 to 37 per cent., while in a black limestone from the grauwacke it amounted to only 0·7 per cent. It would appear, therefore, that between such pure limestone and clay-slate there are numbers of intermediate rocks, showing that mechanical and chemical deposition must have gone on together in various proportions.‡ Sauvage § also examined several specimens of grauwacke and clay-slate that contained from 3 to 50 per cent. carbonate of lime.

Richter's‖ observation, that in the Devonian grauwacke near Saalfeld, the several strata of clay-slate almost always contain at their lower parts, regular beds of rounded limestone shingle is worthy of attention. Where this shingle is very small and crowded, it forms an excellent marble. It generally contains remains of cephalapoda, the interior parts of which are often filled with slate substance. The outer parts are filled with almost pure compact limestone, so that it would seem that these fossils were included in the mechanical sediment after the deposition of the carbonate of lime.

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* Verhandlungen, etc. Jahrg. x, p. 228. In these analyses, the direct estimation of carbonic acid seems to have been neglected.

† Op. cit.

‡ See ante, pp. 22, 131, and under Schalstone, Chap. 55.

§ Op. cit.

‖ Op. cit. p. 23.

C.—*Alum-Slate.*

	XXVII.	XXVIII.	XXIX.	XXX.
Silica	50·13	52·30	59·86	65·44
Alumina	10·73	21·67	15·89	14·87
Peroxide of iron	2·27	5·83	0·50	1·05
Lime	0·40	1·00	0·99	0·15
Magnesia	1·00	2·16	1·68	1·34
Potash	..	..	3·72*	4·59
Soda	..	..	..	0·48
Iron pyrites	7·53	10·17	Sulphur 0·82	1·25
Carbon	22·83	0·80	8·65	..
Water	2·21	5·08	6·90	..
	97·10	99·01	99·01	89·17

	XXIX A.	XXX A.	XXXI.	XXXII.
Silica	71·72	71·72	72·40	69·71
Alumina	19·04	..	16·45	13·59
Peroxide of iron	..	9·06	..	..
Iron pyrites	1·58	..	2·26	7·77
Lime	1·19	..	0·17	0·23
Magnesia	2·02	..	1·48	2·65
Potash	4·46	..	5·08	3·79
Soda	Spur	..	0·53	0·46
Sulphur	..	4·15	1·25	2·30
	100·01	..	99·62	100·50

XXVII. Alum-slate from the transition series, Garnsdorf, near Saalfeld } O. L. Erdmann.†

On the roof of the adit driven into this slate there are almost everywhere yellow or white opaque stalactites, and more rarely a green transparent deposit is produced. Both consist of hydrated basic sulphate of alumina and peroxide of iron. In the former oxide of iron preponderates, in the latter alumina. Both substances are quite insoluble in water.‡

XXVIII. Alum-slate from Wezelstein, near Saalfeld } Erdmann.§

This slate also yields an afflorescence, but was essentially the same composition.

When slate contains sufficient organic substance and sulphates, the whole of the peroxide of iron it contains may be converted into iron pyrites. If this is again oxidized by water permeating the slate, the peroxide of iron is removed in solution, and there remains clay quite or almost free from iron.

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* With some soda.

† Journ. f. Techn. Chemie, xiii, 108.

‡ Ibid., xi, 99, and Journ. für Chem. und Phys. lxii, 104.

§ Op. cit. xiii, 108.

XXIX. Alum-slate from Bornholm. Forchhammer.*

Forchhammer endeavours to show that this slate has been produced from sea-weed at the bottom of the ocean, and that its production may be still going on. By the rotting of this sea-weed its sulphates would give rise to iron pyrites, and the residue mixed with clay would yield alum-slate. But the suspended substance of rivers would furnish material for the production of alum-slate, when it contained as much organic substance as that of the Vistula, and when brought in contact with the sulphates of sea-water.

XXX. Alum-slate from Opsloe, near Christiania } Forchhammer.

Very remarkable alterations of the alum slate along the foot of the Egeberg, eastward of Christiania, are described by Forchhammer.† In the first stage of the alteration it appears very anthracitic, and has generally lost the whole of its water. In the second stage it appears as a black, hard rock, traversed by veins of quartz. In the third stage it appears as gneiss, with a quantity of dark-coloured laminæ of mica, and black laminæ of a graphitic substance.

XXIX A and XXX A. The above alum-slates after deducting the water and carbon.

XXXI. Another alum-slate from Bornholm.

XXXII. Gneiss from Bugten.

It contains dark-green mica, white felspar, quartz, and small cubes of iron pyrites disseminated through the mass, and originating ferruginous alum-slate. This gneiss is situated next to the above-mentioned black rock, and is intimately connected with it.

The close resemblance in composition between the alum-slate and gneiss renders the conversion of the former into the latter intelligible. It would be superfluous to bring forward arguments against Forchhammer's opinion that this alteration has been effected by the very numerous veins of trapp and eurite that traverse this alum-slate, as the untenable character of such hypothesis has been repeatedly shown.

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* Berzelius Jahresbericht, xxv, 404.

† Report of the British Association for 1844.

The numerous small veins of quartz in the black rock, which Forchhammer supposes have originated from the protrusion of the greenstone, most likely originate from silica that has been eliminated in the course of the alteration. At least the gneiss XXXII has a smaller amount of silica than the alum-slate. The presence of sulphur in this gneiss, and of carbon in the gneiss at Egerberg, is directly opposed to the idea of metamorphism by igneous action.

Clay-Slate of older Geological Series.

	XXXIII.	XXXIV A.	XXXIV B.	XXXV.	XXXVI.
Silica	61·72	64·96	66·82	58·50	76·19
Alumina	19·55	18·75	18·45	19·56	9·77
Protoxide of iron ..	8·55	..	..	..	..
Peroxide of iron ..	..	1·39	1·34	13·10	4·29
Lime	0·55	..	..	..	..
Magnesia	1·08	1·98	1·25	3·71	1·33
Potash	4·81	5·92	3·55	2·65	3·82
Soda			1·59	2·89	1·39
Loss by ignition ..	3·74	3·78	3·78	4·09	1·45
Carbon	..	3·22	3·22	..	..
	100·00	100·00	100·00	99·50	98·24

XXXIII. Clay-slate from below Rothwaltersdorf.

This slate is very pure, shining, and blueish-black. It effervesces slightly with acids, and does not feel gritty when rubbed in a chalcedony mortar, so that it seems not to contain quartz. It did not give off water at 212° Fahr. By ignition it became brown, owing to the combustion of carbonaceous substance. The lime was in the state of carbonate.

The composition of this slate is different from that of fossiliferous clay-slate, but it agrees very closely with that of the slate from the Selkethal.

XXXIV. Blueish-black clay-slate from the oldest non-fossiliferous transition formation at Bloomsten, Hardomgerfjild, in Norway } Kjerulf.

XXXV. Shining slate, or semi-crystalline mica-slate from Haartoigen, Hardomgerfjild } Kjerulf.

XXXVI. Quartzose mica-slate from Naesodden, near Christiania.

The mica in this slate is silver-white.

The slate XXXIV passes into the slate XXXV. In the analysis XXXIV A, carbonate of potash was used, and in XXXIV B, hydrofluoric acid was used for decomposing the slate.

The composition of XXXIV approximates to that of the palæozoic clay-slate, especially that of Deville.[*] There appears, therefore, to be no essential difference between these kinds of slate. The alkalies, alone, are in greater proportion in the former than in the latter. Consequently, the suspended substance that furnished the material for both must have been of much the same character. The considerable amount of carbon in the older slate shows decidedly that it was formed subsequent to the appearance of vegetation on the earth.

The difference between XXXIV and XXXV is remarkable, especially as regards the amount of iron, although these slates pass into each other. There is, however, no difficulty in understanding that, in the presence of organic substance, the oxide of iron would be reduced and removed by water, giving rise to the production of iron ores in beds and veins. Hence, it will be apparent, that similar geognostic conditions may be accompanied by very dissimilar chemical conditions, while, at distant localities and in different sedimentary periods, the same chemical phenomena may take place.

The mica-slate XXXVI can have originated only from quartzose clay-slate or grauwacke. The large amount of alkalies in XXXIV and XXXV would render these slates capable of conversion into mica-slate less readily in the case of the latter, on account of the preponderance of soda, though XXXVI also contains a considerable amount of soda.

Shale and Clay-Stone.

	I.	II.	III.	IV.	V.
Silica	61·91	67·35	68·50	72·94	75·01
Alumina	21·73	20·66	18·10	16·66	17·57
Protoxide of iron	4·73	..	..	5·61	..
Peroxide of iron	..	2·55	3·62	..	1·02
Lime	0·09	trace	trace	..	0·23
Magnesia	0·59	0·31	0·52	0·85	0·24
Potash	3·16	..	..	1·40	..
Soda	0·25	..	..	0·75	..
Organic substance	0·70	..	..	..	..
Water or loss by ignition ..	6·73	6·70	7·78	2·20	6.30
	99·89	97·57	98·52	100·41	100·37

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[*] *See* ante, p. 126.

	VI.	VII.	VIII.	IX.
Silica	74·42	85·65	81·05	74·23
Alumina	9·99	10·58	11·49	14·77
Protoxide of iron	5·03	..	2·28	..
Peroxide of iron	..	1·03	..	1·31
Lime	0·29	..	0·40	..
Magnesia	1·12	0·35	0·40	1·35
Potash	4·74	0·52	2·07	1·34
Soda	0·75		2·56	4·80
Loss by ignition	2·34	1·87	0·93	0·99
	98·59	100·00	101·18	98·79

	Analyzed by
I. Shale from the underlying bed of a coal-seam in England	Frankland.*
II to V. Shales from the Saarbrucken coal-measures	G. Bischof.

II, IV, and V were the underlying beds of coal-seams; III was from the middle of a coal-seam; II and III were coloured grey with carbonaceous substance; IV was pale green; and V was almost white.

VI. Green clay-stone from the vicinity of Reitershofes, Rhenish Bavaria	G. Bischof.
VII. Do. do. from a melaphyr quarry at the Donnersberg, near Dannenfels, Rhenish Bavaria	
VIII. Felspar porphyry from Donnersberg, near Falkenstein	
IX. Do. do. from Gottesgab, in Silesia	

The close resemblance between VII and VIII, as well as the local association of these shales, induced me to place them side by side with IX, which presents a striking similarity in appearance to VIII. It is quite conceivable that the clay-stone No. VII may have originated from the porphyry No. VIII after the abstraction of the greater part of the alkalies from the latter by water. On the other hand, the clay-stone VI contains a greater amount of alkalies than either specimens of the porphyry. In any case, there is an unmistakeable similarity between these clay-stones and porphyry; and this similarity is also recognizable from the analyses of porphyry by Schweizer, Kersten, and Wolff.

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* Memoirs of the Geol. Survey of Great Britain, i, 479.

	X.	XI.	XII.	XIII.	XIV.
Silica	77·03	75·44	62·78	68·28	64·80
Alumina	14·06	17·09	25·48	20·00	24·47
Peroxide of iron	1·35	1·13	1·25	1·78	1·72
Lime	0·35	0·48	0·36	0·61	1·08
Magnesia	0·47	0·31	0·47	0·52	0·87
Potash	1·26	0·52	2·51	2·35	0·29
Water	5·17	4·71	6·65	6·39	6·72
	99 69	99·68	99·50	99·93	99·95

X to XIV. Clays from the Duchy of Nassau. Fresenius.*

After the mechanical separation of the sand from the argillaceous substance and drying, it was found to contain traces of soda, protoxide of manganese, ammonia, sulphuric and phosphoric acids, chlorine and organic substances.

Deducting the sand and the free hydrated silica in these clays, the residues correspond so very closely in composition with kaolin, that they may be regarded as originating from the decomposition of felspar. Comparing these clays with shale, it will be seen that both classes of mechanical deposits do not differ more in regard to chemical composition than they do among each other, notwithstanding the great differences in their locality and age. The shale V and the clay XI correspond as closely in composition as different parts of a crystalline mineral.

In like manner, it is not possible to draw any precise distinction between shale and clay-slate; the slate VI and the shale IV are almost identical in composition. A small amount of oxide of iron is not peculiar to shale; for, in the coal-measures of Saarbrücken and other localities, highly ferruginous shale alternates with shale almost free from iron. Silicates of alumina, mixed with more or less silicate of iron, constitutes the chief mass of all argillaceous slates and clays.

The amount of free silica varies very much; it increases in grauwacke until the rock passes into siliceous slate or sandstone.

Just as in the suspended substance of rivers and their deposits, the amount of alkaline and earthy silicates is proportionately very small, so is this the case with argillaceous slates and clay. The fact that the amount of lime is always less than that of magnesia or of alkalies, is consistent with the more easy decomposition of the silicate of lime. By far the greater portion of the silicate of lime, so abundantly present in some rocks, such as augitic and hornblendic rocks, is converted into carbonate of lime, and as such conveyed in solution to rivers, and thence into the ocean. This circumstance is quite consistent, also, with the generally decided separation between mechanical and chemical deposits.

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* Jahrbücher des vereins fur Naturkunde in Nassau, 1852, p. 154.

When the suspended substance, originating from clay-slate, again furnishes, in the ocean, material for the production of argillaceous slate and clay, these deposits will contain still less silicate of lime than the clay-slate. Such a decrease of silicate of lime is recognizable in shale, the material of which may have been derived from the disintegration of clay-slate.

CHAPTER LII.

GRANULAR LIMESTONE.

THIS rock often occurs as beds, sometimes constituting the rock adjoining dykes, also as a petrifying substance, and as the mass of dykes. The first three conditions are indicative of its origin from sedimentary limestone, except perhaps in the case of subordinate beds in crystalline slates, where the carbonate of lime may have originated from the decomposition of calcareous silicates. The granular limestone in dykes can have originated only in this way, by deposition from calcareous water.

Granular limestone often contains a great variety of imbedded minerals; it also contains admixtures of other substances disseminated through its entire mass, and this appears to be connected with its imperfect crystallization, which is the chief difference between it and calc-spar. In calc-spar the amount of impurities is rarely more than 3 per cent., consisting of magnesia, protoxides of iron, and manganese, the bases isomorphous with lime. They are also in the state of carbonates, except when the latter have been peroxidized. There is only one case recorded in which calc-spar was found to contain 1·85 per cent. of silica.* On the contrary, granular limestone generally contains admixtures of siliceous substances to a greater or less extent. The ammonite marble of the Bavarian Alps contains a siliceous clay coloured with oxides of iron and manganese; the marble at Neubeuern leaves, on treatment with acids, 10 per cent. of translucent opaline quartz granules; and the marbles of Aussee, Hallstädt, Adnet, and Kälberlstein, leave copious reddish-brown argillaceous residues.[*] The granular limestone at Auerbach leaves only 0·66 per cent. of a brown quartzose residue; while the calc-spar, occurring at the same place, is completely soluble in acid. Magnesian limestone from the upper beds in Yorkshire[†] left 4·5 per cent. insoluble residue; that from a lower bed only 0·5 per cent.; white chalk 1·1 per cent.; and the mountain limestone and oolite of Yorkshire, none. Werther[‡] found that a specimen of nummulite limestone contained 14·4 per cent. of small rounded quartz granules.

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* Hochstetter.—Journ. für prakt. Chem. xliii, 316.

The following analyses show the differences that prevail in this respect:—

	I.	II.	III.	IV.	V.
Carbonate of lime	99·263	99·010	97·040	82·10	87·49
„ magnesia ..	0·284	·521	2·109	..	..
„ iron	..	..	..	2·59	0·47
Protoxide of iron and phosphoric acid ..	0·251	·062	0·360	..	..
Portion insoluble in acids ..	..	..	..	15·31	12·04
Silica	..	..	traces	..	..
	99·771	99·593	99·509	100·00	100·00

	Analyzed by
I. Fine-grained white marble from Carrara	C. G. Wittstein.[§]
II. Crystalline marble from Schlanders, in the Tyrol	
III. Compact marble from the same place	

IV. Granular limestone from Ober-Schmottseifen.

Grey, with white patches; traversed by layers of thin laminæ of mica, in a direction corresponding with the schistose structure. The fragment analyzed was picked out as free as possible from mica. The insoluble portion consisted of very small laminæ of mica and quartz-sand.

V. Pale red granular limestone with greenish mica.

The insoluble portion consisted of mica and quartz. This rock is, properly speaking, an intimate mixture of granular limestone with mica-slate.

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[*] Schafhäutl.—n. Jahrb. für Min. etc., 1848, p. 147.

[†] Johnstone, ibid. 1845, p. 842.

[‡] Ibid. 1845. p. 671.

[§] Buchner's Rep. iii, 24.

The granular limestone of Carrara is described by Hoffman[*] as gradually passing into compact fossiliferous jurassic limestone, in such a manner that the connection between their origin is unmistakeable. He expresses[†] his astonishment at meeting with clay-slate, mica-slate, talcose-slate, and gneiss, situated in such positions, as regards fossiliferous limestone, as to leave no doubt of their connection and of the simultaniety of their formation. The slates not only follow immediately and regularly after the limestone, but alternate with it, and pass into it and blend with it so intimately, that the latter must be regarded as unquestionably one of the sedimentary rocks. He considers it, as well as the slates and gneiss, to have been metamorphosed by igneous action, and ascribes this result to the protrusion of granite. But at the same time, he adds, that in this part of Italy scarcely any granite occurs, although in this place the valleys are deeply cut.

There can be no doubt that the marble of Carrara is a metamorphic rock; however, this metamorphism has been effected not by imaginary granite, but by the action of water. By this alteration the fossil remains have been obliterated. Bronn[‡] remarks, that the organic substance of animal remains decreases in proportion to the age of the rocks in which they occur, while the amount of carbonate of lime increases, the laminar structure being at the same time rendered less recognizable, or quite obliterated. In the conversion of sedimentary limestone into granular limestone, the fossils are generally quite obliterated, but the bony portions of radiata, etc., are found converted into calc-spar without any vestige of internal organic structure. This change appears to have been produced even in the most recent strata.[§]

These circumstances are indicative of the true nature of the metamorphism of limestone. The organic substance is gradually removed by water, while carbonate of lime is deposited in its place. If this displacement was complete, white granular limestone would be produced, when not complete, grey limestone would be produced. In this manner the origin of the grey streaks, veins, and spots is quite intelligible.

If the calcareous petrifying substance of fossils were only calc-spar or fibrous limestone, objections might be raised against this view of the conversion of compact into granular limestone. But Schafhautl* found the red marble in the Bavarian Alps to consist almost entirely of ammonite chambers, and the marble at Sinning appeared to be a mass of very small fresh-water fossils, chiefly zoophytes. Blum† showed, also, that granular limestone is the petrifying material of a great variety of molluscs in different strata. Granular limestone is most frequent in *polyparia*, sometimes without any vestige of organic structure in the interior, as in the case of the *cyathophyllum* and *calamopora* from the Devonian limestone in the Eifel. Blum points out that the process of petrifaction seems to have been influenced by the character of the rock in which the fossils are imbedded. In rocks of loose structure, through which water could readily penetrate, it was more rapid than in compact rocks. In many instances the production of granular limestone at the inner portions of bivalve shells has been more complete than at the outer parts; sometimes the inside is quite crystalline, while the outside is still compact. Fossils consisting of calc-spar, and others consisting of granular limestone, occur in the same strata at different levels, and sometimes the same fossil presents both granular limestone and calc-spar, so that this circumstance cannot have had any influence on the nature of the petrifying material.‡

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[*] Jahrb. f. Min. etc., 1833, p. 103.

[†] Karsten's Archiv. f. Min. vi, 258.

[‡] Geschichte der Natur. ii, 673.

[§] Blum.—Nachtrag. etc., p. 157.

With regard to the production of calc-spar in the wet way, there cannot be any doubt, and it has already been pointed out§ that the difference between calc-spar and granular limestone consists merely in the one being perfectly, and the other imperfectly, crystallized. This difference is certainly due to the material from which the crystallization took place.

The production of granular limestone in the above instances is quite irreconcileable with the action of heat. Nor can pressure‖ alone be supposed to have exercised any influence, for mere pressure does not produce chemical alteration. Bunsen¶ found that apophyllite powder was not at all affected by water under a pressure of seventy-nine atmospheres, maintained for an hour, unless heat was applied at the same time. Palagonite powder was, also, but very slightly dissolved under a pressure of 103 atmospheres, although, by boiling with water at the ordinary pressure, it is decomposed and dissolved to a much greater extent. In fact, there is no evidence at all to show that pressure alone is capable of influencing in any way chemical action, or of effecting more than a modification of the state of aggregation in gaseous or liquid masses.*

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* n. Jahrb. f. Min. etc., 1846, p. 645; 1848, p. 137.

† Op. cit. p. 167.

‡ English edition, ii, 99.

§ See ante, p. 140.

‖ Cotta—n. Jahrb. für Min., etc., 1850, p. 312. See also Sartorius v. Waltershausen—Physich.-Geogr. Skizze von Island.

¶ Ann. der Chem. und Pharm., lxv, 82.

But passing from laboratory experiments to the products of active volcanoes, it will not be found that there is any greater evidence in support of plutonic doctrines. Thus, the blue limestone found among the materials ejected from Vesuvius, contains, according to Klaproth,† a considerable amount of water, and much less carbonic acid than limestone does. Rammelsberg‡ represents it as a compound of two equivalents of carbonate of lime, and one equivalent of hydrate of lime, which, according to Fuchs, results from the exposure of burnt lime to the atmosphere. Hence it may be inferred, that this limestone was deprived of its carbonic acid by the heat in the volcano, and has absorbed carbonic acid and water since it was thrown out. The presence in it of 0·25 per cent. of carbon is remarkable, as well as the fact that when heated in a retort ammoniacal water distils off. The organic substance represented by these products could not have existed in the original limestone, for it would have been destroyed by the heat of the volcano. This must have been introduced subsequently, as is the case in many other instances with rocks that have undoubtedly been subjected to the influence of volcanic heat.

In the Pyrenees, where considerable masses of crystalline limestone occur almost without interruption from Perpignan to Bayonne, at the boundary of the secondary rocks, Dufrenoy observed that the compact limestone was converted into marble and dolomite, at those places where it was in contact with the granite dykes, while, at other parts, it was full of fossil remains. Coquand * confirmed this observation, and adds, that the minerals imbedded in the limestone depend upon the nature of the rock with which it is in contact. He infers, hence, that granular limestone is a metamorphic rock; and ascribes the presence of mica in it to the contact with granite. However, beds of granular limestone occur both in the green slates, hornblende slates, and compact limestone of the transition rocks at Glätz; alternating regularly with clay-slate, and passing into it. This limestone is frequently penetrated with mica, and accompanied by schistose rocks consisting of mica and calc-spar, but there is neither granite nor any other massive crystalline rock in contact with it, or occurring for a long distance round.

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* The action of caustic alkalies upon siliceous substances is, in like manner, dependent more upon the high temperature than upon the pressure. The solution of silica prepared according to Siemens' method contains about three or four times as much silica as alkali, and when kept for a time, even in closed vessels, deposits one-third of the silica in combination with alkali, and whatever lime or alumina there might have been derived from the material it was prepared with. It is, therefore, evident, that double silicates may be dissolved by water at a high temperature, and deposited as the liquid cools, but the viscous character of the solution prevents crystallization. When the influence of heat and pressure is continued too long, the interior of the digesting vessel becomes covered with an insoluble crust similar to the above-mentioned precipitate. This takes place even when evaporation is completely prevented, and is due to the combination of the alkaline silicate with a larger amount of earthy bases than it is capable of retaining in solution. It is probable, that by some such means as this, felspar and other minerals may be prepared artificially, as Bunsen has succeeded in crystallizing apophylite.

† Beiträge, v. 91.

‡ Handwörterb. i, 332.

Moreover, it happens that minerals containing silicates of lime—garnet, vesuvian, wernerite, wollastonite, etc.—are remarkably frequent in granular limestone, whether the adjoining rocks contain these minerals or not. It would be quite inconsistent with all known facts to regard these minerals as products of sublimation, or of the action of heat in any way, either under great pressure or without.

The calcareous slate in the gorge of St. Ullrich † is converted into a very hard hornstone, where it is in contact with the melaphyr dykes, while, below Predazzo, the shelly limestone is slightly crystalline only for one or two inches, where it is in contact with melaphyr dykes. The limestone occurring in the island of Bute, is also somewhat granular where it is in direct contact with basaltic greenstone dykes; and, according to I. Pryce,‡ it contains only 2 per cent. of magnesia, while the other portions of the rock contain from 17 to 18 per cent. There is a similar difference in the amount of magnesia in the shelly limestone near Predazzo, but to a very much less extent. If magnesia has been removed from the limestone, it could only have been by the action of water, and the presence of the greenstone dykes would have contributed to this result only in so far as water would permeate more readily at and near the points where they were situated, than through the limestone itself. If this was the case, it might also be supposed that the granular condition of the limestone at these parts was produced by deposition of carbonate of lime from the water. This action would be the less remarkable, from the fact that the most compact limestone presents some trace of crystalline structure, and since

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* n. Jahrb. f. Min. etc., 1843, p. 844.

† Cotta.—Geolog. Briefe, pp. 186 and 194.

‡ Phil. Mag., No. 234.

the carbonate of lime in coralline limestone gradually passes into an aggregate of calc-spar crystals.*

It is, however, difficult in any way to account for the removal of magnesia. Unless it were replaced by lime, the altered limestone would be rendered porous; but though bitter-spar occurs pseudomorphous after calc-spar, the reverse case has not been observed.

The conversion of the calcareous slate into hard hornstone, indicates a penetration of silica, and the displacement of carbonate of lime by silica, may be supposed to have taken place, since pseudomorphous quartz, with the form of calc-spar, does occur;† and it has already been sufficiently shown that this alteration could take place only in the wet way.

According to the observations of v. Dechen, the rocks in contact with the melaphyr dykes in the carboniferous district of the Nahe and Saar, are generally quite unaltered. It is only the fragments of shale imbedded in the mass of the dykes that are converted into siliceous slate, or clay-stone, showing that silicification similar to that mentioned by Cotta has taken place. This silicification may be partially due to decomposition of the melaphyr, for just as quartz occurs as a product of decomposition in drusy cavities, veins and nodules in augitic labradorite rocks, so, in like manner, it may have been carried into the rocks adjoining the melaphyr.

W. Fuchs ‡ also observed limestone and dolomite in contact with melaphyr, but not at all altered. The same is the case with the syenite of Monzoni, and also with the porphyry of the Fassathal. Girard § mentions that hyperite traversing limestone in the vicinity of Elbingerode, does not appear to have produced any alteration in the latter, the two masses appearing sharply separated. This is also stated by Cotta to be the case with the limestone and granite near Predazzo. It is added, also, that the granite often extends into the limestone, and that these veins of granite, distinct where they leave the principal mass, gradually become more talcose as they extend into the limestone, and soon pass into serpentine, which traverses the limestone in many places. At the line of contact with granite, the compact limestone is distinctly converted into white crystalline marble containing, according to Petzholt, 32 per cent. carbonate of magnesia, and some 7 per cent. water. This magnesian limestone is called by him, predazzite, and it corresponds very closely with the bitter-spar which Klaproth* called gurofian, except that the latter does not contain any water. This mineral occurs as veins in serpentine, sometimes blended with thin laminæ of talc, and is certainly a product of the action of water. But if this gurofian, occurring in a rock that contains 13 per cent. of water, is anhydrous, it would be very remarkable that predazzite, supposed to be produced by igneous action, should contain water.

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* Naumann—Lehrb. d. Geognosie. i, 441 and 663.

† Blum.—Die Pseudomorph. p. 231, and Nachtrag, p. 135.

‡ Die Venetianer Alpen, 1844, p. 14.

§ n. Jahrb. f. Min. etc., 1848, p. 263.

Cotta believes that a comparison of the conversion of shelly limestone into crystalline marble, the partial conversion of compact limestone into granular limestone in contact with melaphyr dykes, and the analogous instances in the island of Bute, can leave no doubt that high temperature, combined with pressure, were the causes of the alteration. But this comparison alone suffices to show that the supposed influences of contact with granite and melaphyr present totally different conditions; for, while the limestone in contact with granite contains 32 per cent. carbonate of magnesia, that in contact with magnesian melaphyr appears to have lost 15 or 16 per cent. of magnesia. So, likewise, the limestone in contact with melaphyr, which does not contain any uncombined silica, is silicified at the line of contact, while that in contact with quartzose granite is not silicified. Deficient as the chemical data relating to these phenomena are at present, the above facts are sufficient to show how unfounded is the opinion that the alteration of limestone is the result of plutonic action.

Regarding the mass of granitic dykes as a product of crystallization from water, it is obvious that enormous quantities of water must have penetrated through the fissures before either the mass they contain could be deposited, or an amorphous mass could be converted into a crystalline state. Then it is quite conceivable that the adjoining rock would also be permeated by water; but since this rock consisted of substances entirely different from the minerals constituting the dyke mass, the permeation of water would have given rise to crystallization of quite different minerals in the rocks.

Beyond stating that at Predazzo, quartzose granite traverses the limestone, and that predazzite and serpentine have been produced, Cotta does not offer any explanation of the origin of the serpentine. Granite and serpentine are so totally different, that the most active imagination could hardly conceive the conversion of the one into the other by the action of heat. Granite without magnesian mica, such as occurs most generally, is deficient of the chief constituent of serpentine. On the other hand, serpentine contains water, which is not the case with unaltered granite. Even in the wet way it would be difficult to account for the conversion of granite into serpentine.

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* Beiträge, v, 103.

With regard to the origin of granular limestone in dykes, that occurring near Auerbach, in the Bergstrasse, will serve as a good illustration. There enormous dykes of granular limestone traversing gneiss, are quarried. At the upper side of the dyke the limestone is quite white, while at the underlying parts of the dyke it is greyish-blue, owing to the presence of organic substance; and when heated out of contact with the air gives off a mixture of carbonic acid and carbonic oxide. If this dyke had been formed by the protrusion of melted carbonate of lime, this organic substance could only have been introduced subsequently by means of water. Other characters indicate the action of water; thus the large masses of calc-spar in these dykes frequently present surfaces covered with ochre and dendrites, while the cavities are filled with hydrated oxide of iron. The limestone, also, is sometimes penetrated throughout with it. At the saalbands the gneiss is much decomposed, and blocks of gneiss imbedded in the limestone are surrounded with an argillaceous deposit.

Those who suppose that granular limestone has been produced by the fusion of compact limestone, would most likely ascribe the metamorphism, in this instance, to the protrusion of an igneous mass, which also determined the production of the gneiss, from a sedimentary rock. But there is no igneous rock to be met with in this locality, and if such a rock does exist under the gneiss it is impossible that its heat was ever sufficient to affect the upper portions of the gneiss laid bare by this valley.

When dykes, or veins, of granular limestone or calc-spar occur in rocks which yield, by their decomposition, carbonate of lime, as in the case of the dyke in melaphyr near Niederkirchen, there can be no doubt as to the source of the carbonate of lime. But, when the adjoining rock does not contain silicate of lime, as in the case of the gneiss at Auerbach, the source of the carbonate of lime must be sought elsewhere. In the quarry at this place, the granular limestone is in contact with loess—a marl which effervesces copiously with acids. Upon the ridges between the Schönberg and Fürstenlager valleys, this marl occurs at the highest points and at levels much above the granular limestone. Upon the declivity of the Hochstädt valley, at no great distance from the limestone quarries, there is a basalt quarry presenting regular and almost horizontal columns. All the interstices between the basalt are filled with carbonate of lime, which also extends into cracks and covers the surface of the basalt. The basalt is rarely sound, and the fresh surfaces of fractures generally effervesce copiously with acid. At some places, the carbonate of lime resembles granular limestone, and cavities of a few lines' width, are lined with calc-spar crystals. Consequently there was no deficiency of material for the production of granular limestone. It is also worth mentioning, that the water of the mineral spring at Auerbach is rich in carbonate of lime, and that the water of the spring at Hochstädt, which is not far from the limestone quarry, deposits a considerable quantity of ferruginous ochre, similar to the deposit found in the granular limestone.

The production of granular limestone from this marl, is certainly more probable than the protrusion of melted limestone from the interior of the earth. The difference in the age of these deposits is in no way opposed to the former view, for the fissure in the gneiss may have been formed long after the deposition of the marl.

Comparative analyses of sedimentary and granular limestone, taken from localities where they pass into each other, would be of great service in elucidating the formation of granular limestone.

Since granular limestone contains imbedded in it a great variety of minerals—mica, hornblende, augite, garnet, vesuvian, wernerite, wollastonite, felspar, etc.—it follows that the granular limestone in which they occur must have originated from limestone containing silicates. Limestone so pure as that above mentioned from Yorkshire could not have furnished granular limestone containing such minerals, unless the constituents of the latter were supplied by water permeating the rock.

It appears, therefore, that while calc-spar has been produced from water containing, besides carbonate of lime, only a very small proportion of other carbonates or of silicates, granular limestone has been produced from water containing silicates also. In this way the occurrence of pure calc-spar in nests, cavities, and veins in impure granular limestone, may be accounted for as having been deposited from water that dissolved only carbonate of lime. It would, also, account for the fact that sedimentary limestone containing silicates is converted, not into calc-spar, but only into granular limestone, for it would be impossible for water to remove the silicates and leave the carbonates. Since the water permeating such limestone would sometimes dissolve pure carbonates, sometimes both carbonates and silicates, it may be understood why fossil shells are sometimes partly converted into calc-spar, and partly into granular limestone; and also why stalactites sometimes present a very coarse-grained structure, and sometimes consist of calc-spar.

In accordance with these considerations, the granular limestone at Auerbach must be regarded as a deposit from water containing silicates as well as carbonates; and the pure calc-spar occurring in it as a deposit from water that did not contain silicates.

It has already been remarked, that if granular limestone is regarded as a product of limestone melted by volcanic heat,* the wollastonite and other minerals occurring in it, must also be regarded as products of the same action. But there is, indeed, no case in which the origin of wollastonite in the wet way can be more easily accounted for than in granular limestone, since the water permeating it would be deprived of its carbonic acid so as to dissolve silicate of lime without decomposition. The circumstance before referred to † as remarkable, that wollastonite occurs only in granular limestone, and not in sedimentary limestone, now appears intelligible; for, so long as the more easy metamorphosis, —the mere alteration of the state of aggregation of the sedimentary rock,—had not taken place, the more difficult metamorphism, consisting in the segregation of the minute proportion of silicates disseminated throughout the whole mass and the production of distinct minerals, could not have taken place. But there is nothing opposed to the opinion, that the production of the granular structure, and the separation of the silicates, took place simultaneously, by the action of water.

Some layers of the deposit on the thorn faggots at the Nauheim salt works consist of perfectly granular limestone, very similar to that of Auerbach, except that the latter is somewhat more coarse-grained. It generally appears as concentric rings, either coloured yellowish by oxide of iron or nearly white. Here and there are small drusy patches. The brine from which this deposit is produced is remarkable in containing but little sulphate, and very much bicarbonate of lime. The calcareous deposit from the brine at

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* Leonhard.—Lehrb. der Geognosie u. Geol. 1847, p. 639.

† English edition, ii, 123.

Neusalzwerk* consists of carbonate of lime mixed with so much oxide of iron that it appears like ochre. It is friable and earthy, with a few concentric rings of compact brown iron ore. There can be no doubt that the large amount of oxide of iron has hindered the production of a crystalline, or even granular state of the carbonate of lime. The deposit from the brine at Höppe, near Werl, is very ferruginous, and quite compact. The calcareous sinter of stalactites is sometimes very granular, and there is a great similarity between the travertine of Tivoli† and the calcareous deposit on thorn faggots. Calcareous tufa is, sometimes, very granular.‡

The deposit from the brine at Neusalzwerk never presents a granular structure, even that containing but 3·16 per cent. oxide of iron is quite compact.

The Nauheim brine, at a temperature of 89·6° F., deposits in the part of the channel nearest to the spring, a muddy mass, which, when dried, appears as a light cinnamon coloured powder, consisting, according to Bromeis and Ewald,§ of

Peroxide of iron	49·86
Sesquioxide of manganese	0·40
Carbonate of lime	20·81
Silica	2·81
Water	23·53
Chloride of sodium and other soluble salts	2·59
	100·00

Analyses of other deposits at Nauheim‖ show that oxide of iron is deposited first, and that the subsequent calcareous deposits are more crystalline in proportion to their purity. This fact is further illustrated by the following analyses:—

	I.	II.
Carbonate of lime	98·82	94·31
„ magnesia	0·12	1·35
Peroxide of iron	0·92	2·43
Silica (ferruginous)	0·14	1·91
	100·00	100·00

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* English edition, i, 146.

† Ibid. i, 154.

‡ Naumann.—Geognosie i, 669.

§ Jahresbericht der Wetterau. Gesellsch. f. d. g. Naturkunde, 1848, p. 77.

‖ English edition, i, 189.

I. Deposit on thorn faggots from Nauheim.

II. Deposit on thorn faggots from Höppe, near Werl.

The small amount of magnesia in I is remarkable.[*] The analysis of the Nauheim brine shows that it contains only chloride and bromide of magnesium, but no carbonate. It has already been seen,[†] that the presence or absence of magnesia has not any influence on the development of the crystalline or granular structure. Damour considers predazzite to be white granular limestone, with hydrate of magnesia in the fissures and interstices. According to this, the compact limestone near Predazzo would appear to have been converted into granular limestone by the infiltration of magnesia.

The very minute amount of soluble substance in the deposits from brine would seem to be connected with their dense structure. When it is remembered that calc-spar and other dense minerals in fissures and cavities are rarely produced from such concentrated solutions as the brines, but, on the contrary, from very dilute solutions, it is not surprising that those minerals do not contain any appreciable amount of soluble salts. At the same time the crystalline character of the deposits from these brines shows that the presence of soluble salts does not hinder the crystallization of these minerals.

The silica in both the above deposits is combined partly with magnesia, partly with oxide of iron. In all the analyses of deposits from the water of warm springs, silica is met with to as much as 11·6 per cent., and this silica has most likely been deposited in combination with oxide of iron.[‡] The Nauheim brine deposits the greater part of its silica before the carbonate of lime,[§] so that it appears to be combined with oxide of iron. Even the deposit first formed from the water of cold springs contains some silica with the oxide of iron. All these facts show that a part of the silica is combined with oxide of iron in the water; and since the iron in water is generally in the state of protoxide before it comes in contact with the air, it must exist as protosilicate, one of the most universal constituents of minerals that are produced from water. The presence of silicate of magnesia in the water of springs is equally certain; and hence it appears that the same water that deposits carbonates may yield the material for the production of minerals, either directly or by interchange of constituents. In this case, the carbonates and silicates so frequently associated in fissures and cavities would be products of the same water. Of course the metamorphic changes produced by water which, like the Nauheim brine, deposits different substances in succession, would differ correspondingly according to the conditions to which it was subjected in its passage through rocks; and, consequently, there can be no doubt that white or grey granular limestone, such as that at Auerbach, might be produced by water similar to the Nauheim brine. Nor is the magnitude of the limestone dyke at Auerbach at all inconsistent with such a mode of formation, when it is considered what enormous masses of carbonate of lime are deposited by the water of such springs as that at Nauheim.

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[*] English edition, i, 191.

[†] See ante, p. 145.

[‡] Ibid., i, 149.

[§] Ibid. i, 190; and ante, p. 151.

[||] Johnstone.—Ibid. 1845, p. 842.

G. Rose [*] shows that the arragonite, obtained by precipitation, is readily converted into calc-spar by digesting it with water or with a solution of carbonate of ammonia. Large crystals of arragonite, when heated to redness, crumble into powder of calc-spar. Small ones retain their form, though converted into an aggregate of calc-spar crystals. [†] His experiments also show that both calc-spar and arragonite may be produced from solution according to the temperature at which the crystallization takes place, but that, by fusion, calc-spar only is produced.

Evidence of the production of arragonite from the water of hot springs is afforded by the deposits in the island of Thermia, at Carlsbad, Eubœa, and Œdepsos; and well-developed calc-spar crystals are produced from the water at the Adelsberg grotto, which has a temperature of 59° F. only.[‡]

In digging out a well near Schlackenwerth, Haidinger [§] found, between layers of basaltic tuff, stems of trees from one to eight inches thick, the wood having been replaced by radiated groups of crystals having the form of arragonite, but consisting of aggregates of calc-spar, showing that the arragonite had been altered after its formation. In accordance with G. Rose's experiments, Haidinger assumes that these pseudomorphs have been produced under the influence of a high temperature.

Graf K. Sternberg [||] considers that there was, at one time, a forest on this spot, and that it was buried in the pasty basaltic tuff. It would almost appear that the greater part of the plants decayed gradually, and that the liquid from which the calc-spar and arra-

[*] Poggend. Annal. lxii, 364.

[†] English edition, ii, 43.

[‡] Fiedler.—Pogg. Ann. lxviii, 569.

[§] Poggend. Ann. xlv, 179.

[||] Ibid., xlv, 182.

gonite were deposited, filled the cavities thus formed. Consequently, there is little probability that the basaltic tuff heated the water; for the time over which the decay extended, would be greater than that requisite for the cooling of the tuff.

Haidinger also found pseudomorphous calc-spar with the form of arragonite in a long cavity of a lode near Herrengrund, in Hungary.* The lower parts of the cavity still contain arragonite crystals, which are corroded at some parts, and, at others, covered with microscopic calc-spar crystals.

There are several facts which show that deposition from hot water, is not by any means a necessary condition of the production of arragonite. Thus, Kobell † found that the stalactites in the caves at Antiparos consist of arragonite. Fiedler ‡ adds that, in many instances, the nuclei of these stalactites consist of calc-spar. Some stalactites in North America, consist of radiated arragonite, like that at Antiparos, while others consist of calcareous sinter. Breithaupt § found thick masses of sinter, consisting of many alternate layers of calc-spar and arragonite, in the shaft of a mine near Zwickau, that had not been worked for forty-three years. Difference of temperature could not have had any influence upon the production of these minerals, because the deposit was beyond the reach of such influences. Haidinger also mentions the occurrence of arragonite, associated with calc-spar and fibrous limestone, in the iron-ore deposits of Styria, and Hüttenberg, in Carinthia.

From these facts, it would appear that arragonite may be produced, and also converted into calc-spar, independently of temperature; and that it has generally been deposited from cold water. The conditions which determine the production of one or other minerals are, however, yet unknown.

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* Pogg. Ann. liii, 139.
† n. Jahrb. für Min. etc. 1835, p. 256.
‡ Ibid. 1848, p. 422, and Pogg. Ann. lxviii. p. 567.
§ Pogg. Ann. liv. 156.

CHAPTER LIII.

DOLOMITE.

No rock has attracted greater attention than dolomite. Its purity and crystalline character on the one hand, its distinct stratification in some instances, and the not unfrequent occurrence of fossil remains in it on the other hand, appear as phenomena that cannot be reconciled. The interest excited by this rock was greatly increased by L. v. Buch's careful investigation of the conditions under which dolomite occurs, of its geognostic phenomena as regards other rocks, and by the peculiar hypothesis based on this investigation, according to which its origin from limestone was sought to be explained. The idea of metamorphism had already been formed by Ardaino and Heim;* and the hypothesis put forward by v. Buch was received by some and opposed by others. This was at a time when chemical or physical facts were almost entirely unheeded in geological investigation, when, consequently, the geognost was almost destitute of any basis for the explanation of genetic relations, and when for this reason there was necessarily a greater latitude in accounting for observed phenomena than can be admitted at the present time.

In treating of this rock I shall have occasion to refer to some views relating to the production of dolomite, in which facts and speculation are intimately blended, and which serve to illustrate the insufficiency of all pyrochemical representations of geological phenomena.

Dolomite is of considerable importance as regards the later history of geology. If it always occurred as a massive rock, it is probable that many would not hesitate to class it among eruptive rocks, as is the case with many kinds of granular limestone.† Indications of such a tendency are sometimes to be recognized. However, the opinion that dolomite is an altered rock gradually became more generally received, and since even those geologists that were most inclined to plutonic doctrines were convinced of the impossibility of their application in the case of dolomite, it was attempted to account for the conversion of limestone into dolomite in the wet way by assuming the agency of heat and pressure, as it were for the sake of conciliating those who held extreme views as to the igneous origin of rocks. It does not appear whether these geologists considered limestone to be the only rock that is capable of undergoing alteration by means of water containing carbonates and other salts.

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* Naumann.—Lehrb. d. Geognosie. i, 799, et seq.

† Many of the so-called primitive limestones are really dolomite.

The circumstance that dolomite is sometimes stratified and sometimes not, is of importance, because stratification is indicative of sedimentary origin, and because its absence in dolomite containing organic remains shows that stratification may be obliterated by the alteration of strata. If, therefore, there are any reasons for the opinion that any massive rock has originated from sedimentary strata, the absence of stratification is no evidence against such an origin. The very frequent silicification of rocks adjoining dykes shows, likewise, that by the action of siliceous water all the original structural characters may be obliterated.

It would be very interesting to have comparative analyses of stratified and unstratified dolomite. If it is in consequence of the alteration that the stratification has been obliterated, it might be expected that where this alteration is complete the stratification would have disappeared. Upon this assumption, it is probable that the composition of unstratified dolomite would approximate to equal equivalents of carbonate of lime and carbonate of magnesia, while that of stratified dolomite would present unequal equivalents of these substances.

In describing the dolomite of Eichstädt, L. v. Buch points out the difference between the granular texture of the dolomite and that of limestone. In the former the small crystals of which the mass consists are in contact only at a few points, and the interstices are recognizable by the naked eye. In granular limestone, on the contrary, there are no such interstices, each particle is in close contact with the others that adjoin it.

It is unintelligible how a sediment of such porous character could be formed; but it is easily intelligible how this condition might result from the abstraction of constituents from the rock.

So, likewise, the circumstance referred to by v. Buch, that the caves near Muggendorf are in the dolomite, and that as a general rule they are more frequent in dolomite than in limestone, shows that there is a considerable removal of the material of these rocks.

Leopold v. Buch,* in describing the mountain of Santa Agatha, near Trento,† remarks, "that one is astonished at the remarkable manner in which it is split and fissured." This is still more striking when the surfaces of the fissures are examined. They are everywhere covered with small rhombohedrons, of which sometimes only the edges, corners, and faces are recognizable. When the fissures are wider the rhombohedric crystals are more distinct, and when two fissures intersect, these crystals are united together, forming a mass presenting all the characters of true dolomite, such as that of Tassa. It is evident that a mountain, which has been thus fissured and rent, must have lost every vestige of stratification; it is evident that there were provided in this way thousands of channels for the infiltration of magnesia, and its combination with the limestone; it is evident that in course of time the whole mass would be converted into rhombohedrons, and it is also evident that they could have been in contact with each other only at a few points. Their formation must cease so soon as the limestone mass was all removed, and for this reason it happens that the beds of compact limestone, containing fossil shells, may be converted into an homogenous white granular mass, without any trace of organic remains, or any indication of horizontal structure. A slight reddish colour, such as is recognizable at several places at Santa Agatha, admits of the conjecture that the rock from which the dolomite originated was the red limestone, containing ammonites, which occurs in very thin beds, constituting the greater part of the sides of the valley of Trento. This may be proved by examining the mountain all round, from Danti towards Oltre Castello. There the beds of this limestone, without any sign of alteration, are found to form the back of the mountain. These beds traverse the whole mountain, so that v. Buch is convinced that some strata might be found presenting at their north-western extremity all the characters of the lower chalk series; while at the other extremity they would present that state of decomposition which, probably, precedes the formation of dolomite. As the composition of dolomite has already been treated of,‡ we may at once proceed to the consideration of its production, and of the various views that have been entertained with regard to this question.

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* Ann. de Chim. et Phys. xxiii, 296.

† Geognost. Brief. 1824, p. 16.

‡ English edition, ii, 46.

Haidinger,* guided by the frequent association of dolomite and gypsum, conjectured the magnesia was introduced into the limestone as sulphate of magnesia, and that by the reaction sulphate of lime and carbonate of magnesia were produced. In the total absence of any indications of igneous action, in the instances observed by him, the medium by which this molecular change was effected must have been water, in which sulphate of magnesia is readily soluble, and gypsum sparingly soluble. But since the chemistry of these substances shows that precisely the contrary change takes place, and that a solution of sulphate of lime filtering through dolomite converts it into pure carbonate of lime, extracting sulphate of magnesia, Haidinger assumed that at great depths, and under considerable pressure, the contrary change takes place. He estimates the temperature requisite for this at 392° F., which would correspond with a pressure of fifteen atmospheres. It was, also, found by v. Morlot, that a mixture of one equivalent of crystallized sulphate of magnesia, and two equivalents of powdered carbonate of lime, heated in a sealed glass tube to the above-named temperature, gave a double salt of carbonate of lime and carbonate of magnesia, together with gypsum; and that no trace of sulphate of magnesia remained undecomposed.†

At a depth of about 17,600 feet in the ocean, there would be a temperature of 392° F., if it were not that the temperature decreases in the ocean with the depth, and ultimately falls as low as 36° F.‡ But at the bottom of the ocean at this temperature the decomposition could not take place, and, consequently, there could not be any production of dolomite there. It could only be assumed that the decomposition took place at the same depth in the solid crust of the earth. The possibility that the dolomite of the Tyrol, situated at great heights, was once 17,600 feet below the level of the sea, cannot be exactly questioned, since so little is known of the former condition of the earth's surface, though there would be some difficulty in assuming that there has been so great a denudation of strata as, for instance, at Langkofel, where the dolomite lies nearly 4,000 feet above the level of the sea.

Dolomite, containing equal equivalents of the carbonates of lime and magnesia, would have yielded by the decomposition of carbonate of lime by sulphate of magnesia 62 per cent. of gypsum. Such enormous masses of gypsum would necessarily be found in the vicinity of the dolomite if it had originated in this way. But this is not the case.

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* Poggend. Annal. lxxiv, 591, and n. Jahrb. für Min., 1847, 862. The possible connection between the conversion of dolomite into limestone, and the production of gypsum was pointed out by L. v. Buch, Collegno, and v. Alberti.

† Morlot—n. Jahrb. für Mineral, 1847, 862.

‡ G. Bischof.—Wärmelehre, etc, p. 152.

Haidinger* endeavours to refer the efflorescence of sulphate of magnesia in many of the gypsum quarries of the eastern Alps, as at Füllenberg, near Baden, at Weidmansfeld, near Bernitz, and also the production of calc-spar in drusy cavities, to the decomposition of dolomite by sulphate of lime into carbonate of lime and sulphate of magnesia.

The experiments made by A. Favre and Marignac † are connected with those already mentioned. The latter found that by heating carbonate of lime with a solution of sulphate of magnesia, or of chloride of magnesium, in a sealed tube for six hours, under a pressure of fifteen atmospheres, and at a temperature of 392° F., a portion of the carbonate of lime is converted into carbonate of magnesia and sulphate of lime, or chloride of calcium, and that in this way a double salt is produced, consisting of 48 per cent. carbonate of lime, and 52 per cent. carbonate of magnesia, that is to say, dolomite containing more magnesia than true dolomite. When the mixture was heated only two hours, the product contained less magnesia than true dolomite. Therefore, time is requisite for this alteration; and this is supposed to be the reason why magnesian limestone and true dolomite occur as well as other mixtures in which there is an excess of magnesia.

The hypothesis based on the foregoing experiments assumes that where the dolomite now occurs in the Tyrol, carbonate of lime was formerly deposited, as is indicated by the occurrence in it of *polyparia*, encrinites, and oyster shells, in the Seisser Alps. The sea water contained sulphate of magnesia and chloride of magnesium. During volcanic eruptions sulphurous and hydrochloric acids were generated at the same time that the melaphyr was protruded. These acids, diffused through the sea water, are supposed to have extracted magnesia from the erupted rocks, giving rise to the production of chloride of magnesium and sulphite of magnesia, which, by exposure to the air, became sulphate. It is supposed, also, that this took place at a temperature of 392° F., and under a pressure of fifteen atmospheres, at a depth of 600 feet under the ocean. The cellular character of dolomite, which, according to Elie de Beaumont and Morlot, results from the replacement of lime by magnesia, is considered to prove that the rock has been altered since its deposition, since otherwise it would be compact. There is at many places compact dolomite, which has, probably, been produced directly. But with regard to the enormous masses of Tyrolese dolomite, which are cellular throughout, it cannot be assumed either that they were originally limestone strata, or that they were produced directly. It is supposed to be more probable that the carbonate of lime, after having been precipitated in a pulverulent state, was converted into dolomite, and that in this way the latter became cellular.

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* Poggen. Ann. lxii. 310.

† N. Jahrb. für Mineral., 1849, p. 742.

In the application of chemical experiments for explaining the origin of dolomite or any other geological phenomena, it is above all things necessary that the chemical evidence brought forward should be appropriate, so that those who are but slightly acquainted with chemistry, and are not able to exercise the necessary criticism, may not be misled.

In an hypothesis it is necessary that each assumed condition should be accurately described, and its connection with phenomena proved. In the above instance, the heating of sea water to a temperature of 392° F. is ascribed to volcanic eruptions. Some thirty years ago I endeavoured to account for the temperature of the mineral water of Carlsbad by assuming the existence of a mass of half-melted basalt which was situated near the source of the springs.* However, the experiments by means of which it was attempted to estimate the magnitude of this mass of basalt, afford the means of estimating the mass of sea water that would be heated to a given temperature by a given mass of half-melted melaphyr. Thus, for instance, nine pounds of half-melted melaphyr would heat fourteen pounds of water, or five times its volume, to a temperature of 302° F. But a temperature of 302° F. would be the mean temperature of a column of sea water which, under the pressure of this column, had a temperature of 392° F. at the bottom, and under the ordinary atmospheric pressure had a temperature of 212° F. This fact, that a column of water of considerable height, having a temperature exceeding 212° F. at the lower part, must have a temperature of 212° F. at the upper part, seems to have been overlooked in devising the above hypothesis. If the production of dolomite took place under such conditions, we must suppose that the ocean was boiling, and, consequently, that all the animals it contained would be killed and buried in the dolomite in course of formation.

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* Die Vulcanischen Mineralquellen, etc., 1826, p. 150.

The water of the Mediterranean, which contains the largest amount of magnesian salts, contains 0·525 per cent. chloride of magnesium, and 0·625 per cent. sulphate of magnesia. By the decomposition of these magnesian salts by means of carbonate of lime, there would be produced 0·907 per cent. of carbonate of magnesia, the bulk of which would be 0·302 per cent., and it would furnish 0·58 per cent. dolomite. If, therefore, the entire quantity of magnesian salts in sea water were consumed in the production of dolomite, each hundred cubic feet of sea water would yield only 0·58 cubic feet of dolomite; and for heating that quantity of water 20 cubic feet of half-melted melaphyr would be requisite. The sections given in L. v. Buch's memoir* certainly show that the mass of the melaphyr is generally much greater than that of the dolomite, but at the same time, it is very questionable whether it is so much as thirty-four times greater.

In the above hypothesis it is supposed that the hydrochloric and sulphurous acids extract magnesia from the erupted rocks; but this is a very awkward feature of the hypothesis, for these acids would also extract other bases besides magnesia, producing chloride of iron, sulphite of iron, etc., which would be again decomposed by carbonate of lime. Consequently, the dolomite would have been mixed with considerable quantities of hydrated peroxide of iron. However, it happens that dolomite either does not contain any iron, or only very small quantities. Lastly, the dolomite thus produced would have been mixed with gypsum, for by the conversion of the sulphate of magnesia there would have been 0·705 per cent. sulphate of lime produced, increasing the amount of this salt in sea water to 0·72 per cent., so that about 0·5 per cent. must have been precipitated.

These remarks will be sufficient to show the untenable character of this hypothesis.

Forchhammer† is of opinion that carbonate of magnesia was deposited from the water of springs chiefly where the carbonate of lime in it was decomposed by the reaction with the magnesian salts in sea water. According to his observations, the carbonate of magnesia is always deposited, in such instances, together with some carbonate of lime. When water containing only carbonate of lime is mixed with boiling sea water, the precipitate produced contains 12·23 per cent. carbonate of magnesia, and 87·77 per cent. carbonate of lime. The proportion of magnesia appeared to increase as the temperature was raised, and hence it was inferred that high temperatures may have prevailed during the production of dolomite. When the water contained carbonate of soda besides carbonate of lime, the proportion of carbonate of magnesia in the precipitate was increased to 27·93 per cent. in one instance.

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* Ann. de Chim. et de Phys., xxiii, pl. 3.

† Op. cit.

Forchhammer endeavours, therefore, to refer the origin of dolomite to such a reaction of spring water with sea water, instead of to an alteration of limestone. Since, however, this hypothesis requires that the sea water should be hot, and since the precipitates obtained did not contain so much magnesia as dolomite, it must be regarded as equally untenable with that before mentioned.

Grandjean* attempts to account for the production of the dolomite in Nassau by assuming that the excess of carbonate of lime has been extracted from the black transition limestone containing magnesia.

In connection with the above views are some very interesting remarks of Nauck's, in his memoir on the steatite at Göpfersgrün.†

In the drusy cavities of the dolomite, which at that place is very much fissured, there are besides crystals of bitter-spar very frequently druses containing quartz. If the silica of which these consist had the same origin as the bitter-spar crystals, silica would have been extracted from the dolomite by water. This is quite in accordance with the rare occurrence and very small amount of silica in this dolomite, while the limestone, from which it may be assumed this dolomite was produced, contains silica much more frequently and in larger amount.

Excluding from among the analyses of dolomite given by Rammelsberg the black dolomite, which may be regarded as a special variety, there is only one—the dolomite of La Spezzia—which contains silica, 0·5 per cent. Among the ninety-six kinds of dolomite analysed by Karsten, there were seventeen that did not contain any silica, and thirty in which the quantity of silicates did not amount to 1 per cent. It is very rarely that there is any considerable amount of foreign admixture in dolomite. The dolomite of Minas Geraes, in Brazil, contains 14·2 per cent. of quartz and mica; a dolomite near Tarnowitz, Upper Silesia, contains 15·8 per cent. of clay, etc. It is, however, worth noticing, that all the forty-eight specimens of dolomite from near Tarnowitz contained silicates, or some other admixture. Since with the exception of six of these they contained less, and sometimes considerably less, carbonate of magnesia than dolomite, it might be conjectured that their formation has not yet been completed, and, consequently, that the admixtures originally present have only been partially removed. Indeed, those six specimens in which the carbonate of magnesia was nearer to the normal amount, contained but very small quantities of admixtures.

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* N. Jahrb. für Mineral., etc., 1844, p. 543.

† Poggend. Annal., lxxv, 129.

Comparing the numerous analyses of shelly limestone with these analyses of dolomite, it appears that two from the Teutoburg forest contain* 9 and 10·7 per cent. of silica; that fourteen from Franconia† contain from 1 to 6·5, and on the average 3·3 per cent.; and one from Saarbrücken ‡ contains 2·6 per cent. On the other hand, Abich § found in the analyses of six specimens of Appennine limestone only one that contained silica.||

The pseudomorphous steatite, after quartz and after bitter-spar, occurring at Göpfersgrün, indicates that the silicate of magnesia also originates from dolomite, whence bitter-spar and silica has been first extracted by water, and afterwards silicate of magnesia. Some specimens in the king's collection of minerals at Berlin, labelled "steatite from the dolomite at Thiersheim," near Göpfersgrün, prove that the nodular masses of steatite were deposited before the crystals of bitter-spar were converted into pseudomorphs. Therefore the various deposits alternated, which renders it probable that the water always contained the same substances, although, perhaps, in varying proportions; but that according to circumstances, bitter-spar and quartz, or quartz and steatite, were deposited, or the former were displaced by silicate of magnesia.

If, therefore, water extracts from dolomite silica and silicates, the presence of these substances in limestone cannot hinder its conversion into dolomite, for it may be assumed that this extraction takes place simultaneously with the alteration. If, therefore, the analysis of a limestone adjoining dolomite shows the presence of silica, while the latter does not contain any, it cannot thence be

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* Brandes, Journ. für Prakt. Chemie, xix, 477.

† v. Bibra, ibid., xxvi, 8.

‡ Schnabel, Verhandl. d. Naturhist. Ver. d. Preuss. Rheinlande, 1848, p. 150.

§ Geolog. Beobachtungen.

|| In future analyses it would be desirable to estimate the amount of silica in the neighbouring limestone, as well as in the dolomite.

inferred that the dolomite has not originated from the alteration of that limestone.

Nauck described pseudomorphous steatite after calc-spar. The crystals are tolerably large, and very much grown together. The interior consists of small rhombohedrons of bitter-spar crowded together, while the steatite pseudomorphs, after quartz and bitter-spar, do not present any structure at the interior. He regards it, therefore, as probable that these pseudomorphs, after calc-spar, have been produced by two successive changes, the limestone having been first converted into dolomite, and this again converted into steatite.

He considers it also probable, that the original calc-spar crystals have been produced only in fissures of the granular limestone, and not in the dolomite; but at the Göpfersgrün mines dolomite forms only are met with. If, then, it can be assumed, that the calc-spar crystals have been produced in fissures of the limestone and then converted into bitter-spar, it may be inferred, with tolerable certainty, that the dolomite which has been converted into steatite was previously granular limestone. But the other fissured dolomite, which occupies in some parts the place of the limestone, corresponds so closely with the Göpfersgrün steatite, and presents such similar forms, that it must be regarded as having the same origin.

It may be observed in opposition to these inferences, that calc-spar crystals also occur in fissures and cavities of dolomite; consequently that from the mere occurrence of steatite pseudomorphs after calc-spar alone, it cannot be inferred that the dolomite which has been converted into steatite was previously granular limestone. But Nauck's opinion that the conversion of granular limestone into dolomite was effected by infiltration of carbonate of magnesia is certainly the most probable view of its production. The carbonate of magnesia in water permeating limestone strata would affect the production of dolomite in consequence of tendency to the formation of magnesian double salts, and by removing from the limestone the silica it contained.

Since the decomposition of silicate of magnesia, when dissolved in water by carbonic acid, has been proved,* the conversion of silicate of magnesia into carbonate would have taken place prior to the penetration of the water into the limestone strata, and then the production of dolomite would have been effected by this carbonate of magnesia.

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* English edition, i. 3.

The possibility of such a production of dolomite is further proved by the occurrence of pseudomorphous bitter-spar after calc-spar.* v. Morlot† mentions a calculation made by Elie de Beaumont, according to which, on the assumption that of two equivalents of carbonate of lime one equivalent was removed, and one equivalent of carbonate of magnesia deposited in its place in the production of bitter-spar, limestone would in its conversion into dolomite have been reduced in bulk 12·1 per cent. He was induced by this calculation to estimate the actual proportion of hollow spaces in dolomite, to the entire mass. For this purpose he took dolomite of average porosity, and found that the hollow spaces amounted to 12·9 per cent., or very nearly the calculated value. These pseudomorphs occur almost only upon dykes and lodes. Since the passage of water takes place most readily there, Blum is of opinion that water containing carbonate of magnesia has produced this alteration. There cannot be any doubt that this opinion is correct. The carbonic acid, combined with the carbonate of magnesia as bicarbonate, acted upon the carbonate of lime, converting it into bicarbonate, which was removed by the water while carbonate of magnesia was deposited in its place. When the pseudomorphs are hollow, and, as at Schemnitz, consist of very thin shells of bitter-spar, presenting the form of the original calc-spar crystals, without any trace of this substance in the interior, while the inner surfaces of these shells are sometimes quite smooth, sometimes covered with crystals of bitter spar, there can be no doubt that the amount of magnesia must have gradually decreased, and finally disappeared. Then no further interchange could have taken place, and the action of the water would be limited to the solution and removal of the carbonate of lime.

These pseudomorphs are not by any means of rare occurrence. Blum mentions many localities where they occur upon lodes, at Schemnitz and Kremnitz, in Hungary; at the Schlaggenwald, Przibram, and Joachimsthal, in Bohemia; in the Erzgebirge, in Mexico; in the Münster valley, etc. They also occur in drusy cavities in the doleritic conglomerate in the vicinity of Breisach, on the Kaiserstuhl, and in geodes in the amygdaloid rock at Oberstein. It is worth mentioning that only a few forms of calc-spar have undergone this alteration, although those are of the most frequent occurrence, namely the scalenohedron, the obtuse rhombohedron, and the combination of these with the six-sided prism.

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* English edition, ii, 49.

† Poggend. Annal., lxxiv, 591.

If there is a connection between the crystalline form of calc-spar and the liability to alteration, and if this is also the case as regards other minerals, it would account for the fact that the same substances are sometimes differently affected by solvents, according to their external form and internal structure. It is easy to understand that according to the degree of cleavability, and according to the situation of the cleavage planes, the alteration of a mineral would take place in dissimilar degrees.

Blum,* after pointing out the nature of the conversion of calc-spar into bitter-spar, goes on to consider the conversion of limestone into dolomite, and remarks that no positive opinion can be formed on this subject; and that although the conversion of calc-spar into bitter-spar cannot be questioned, the production of dolomite from limestone is less certain because the evidence of form is wanting. It must, however, be remembered, that at the time his work appeared there was much uncertainty as to the mode in which pseudomorphs are produced.

Dolomite presents, in its rent and fissured condition, so great a resemblance to some hollow pseudomorphs of bitter-spar after calc-spar, that this character alone seems almost enough to induce one to regard them as having been produced in the same manner. These pseudomorphs prove positively that crystallized carbonate of lime may, by combination with carbonate of magnesia, be converted into a double carbonate. If this is the case with crystallized carbonate of lime, it would be so likewise with amorphous carbonate of lime, or with compact limestone, which, when examined by the aid of the microscope, presents a crystalline granular structure. Consequently, dolomite would be produced whenever carbonate of lime in any state, is brought into such conditions as are requisite for conversion into double carbonate of lime and magnesia. The essential conditions of this conversion are the permeation of carbonate of lime by water containing bicarbonate of magnesia, which is one of the most common constituents of spring water.

The mode in which this alteration takes place may be represented by the following diagram:—

$$\begin{array}{l}\text{Bicarbonate of}\\ \text{magnesia}\end{array}\left\{\begin{array}{ll}\overbrace{\text{Carbonic acid} \qquad\qquad \text{Carbonate of lime A.}}^{\text{Bicarbonate of lime removed in solution.}} \\ \underbrace{\text{Carbonate of magnesia} \qquad\quad \text{,,} \quad \text{,,} \quad \text{B.}}_{\text{Dolomite remains.}}\end{array}\right\}\text{Limestone.}$$

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* Die Pseudomorphosen, etc., p. 361.

I have taken much pains to effect the decomposition of bicarbonate of magnesia by means of carbonate of lime. A solution of pure bicarbonate of magnesia was prepared by passing carbonic acid through a mixture of carbonate of magnesia and water, and the clear liquid was digested with pure carbonate of lime in a closed vessel. After twelve hours the clear liquid was separated by filtration, and the carbonate of lime washed until the filtrate gave no further indication of magnesia. However, there was neither any lime in solution, nor any magnesia retained by the carbonate of lime. Consequently, the reaction between these substances must be so feeble, that a very much longer time would be requisite for it to take place to any recognizable extent.

Some years ago I made the same experiment with small fragments of chalk instead of powdered carbonate of lime. The closed vessel remained several years unopened, but in examining it from time to time I was unable to observe any action upon the edges of the chalk fragments.

Although the results of these experiments do not furnish any evidence of the conversion of carbonate of lime into double carbonate of lime and magnesia, they do not in any way invalidate the evidence furnished by the occurrence of pseudomorphs of bitter-spar after calc-spar.

Water extracts from a mixture of carbonates of lime and magnesia twenty-eight times as much carbonate of magnesia as carbonate of lime;* consequently, when water containing about equal quantities of these carbonates, evaporates so far that the separation of carbonate of lime commences, the deposition of carbonate of magnesia cannot take place until the water has evaporated to such an extent that there remains only $\frac{1}{28}$ of the water present when the deposition of carbonate of lime commenced. When the amount of carbonate of magnesia is less than that of the carbonate of lime, it is evident that the evaporation must extend still further before the deposition of carbonate of magnesia can commence. Then, since it generally happens that spring water contains less carbonate of magnesia than carbonate of lime, it is clear, that by the evaporation of this water the greater part of the carbonate of lime will be deposited without any trace of carbonate of magnesia being mixed with it. When the water of a spring does not evaporate completely, but if somewhat less than $\frac{27}{28}$ is evaporated, carbonate of lime alone will be deposited, and the whole of the carbonate of magnesia may be retained in solution. If at the same time the deposits from such spring water contain traces of magnesia, its deposition must be attributed to the tendency towards the production of a double salt with carbonate of lime. This may, perhaps, be the case with the dolomitic marl, shelly limestone, and mixtures of limestone and dolomite examined by Karsten. The composition of the deposits from the water of springs shows, moreover, that true dolomite, or the compound of carbonates of lime and magnesia in equal equivalents, is never deposited from water.

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* German edition, i, 875.

In order to elucidate these relations of carbonate of lime and carbonate of magnesia, the following experiments were made.

I. Solutions of carbonate of lime and of carbonate of magnesia, in carbonic acid water, were mixed in equal quantities, and evaporated at a temperature of 122° F. When the volume of the solution has been reduced one-third, the precipitate was analysed, and found to consist of

Carbonate of lime	1·64
„ magnesia	1·99
	3·63

The filtered liquid was again evaporated to one-fifth, and the precipitate, produced meanwhile, was found to consist of

Carbonate of lime	Trace
„ magnesia	0·43

The remainder of the liquid was evaporated to dryness, and was found not to contain a trace of lime, but only 0·84 carbonate of magnesia.

Whether the carbonate of magnesia in the first precipitate was deposited together with carbonate of lime, or after this had been deposited, did not appear from this experiment.

II. Since water containing, like the above solutions, twice as much carbonate of magnesia as carbonate of lime, and both saturated, are of very rare occurrence, the experiment was repeated with the ordinary well water used in the laboratory at Bonn, in which the carbonate of magnesia amounts to about half as much as the carbonate of lime. The quantity of water taken was 80 ounces.

When evaporated at a temperature of 122° F., a film of carbonate of lime collected upon the surface, and

		1·0 oz. of water was evaporated
When		16·3 oz.
The deposit consisted of—		
Carbonate of lime	2·89 grs.	
„ magnesia	trace	
Silica	trace	
When		27·7 oz. more „
The deposit consisted of—		
Carbonate of lime	5·47 grs.	
„ magnesia	trace	
Silica	trace	
When the remainder was evaporated to dryness		35 oz. „
The residue consisted of—		
Carbonate of lime	0·22 grs.	
„ magnesia	1·95 „	
Silica	trace	
		80 oz. „
The total amount of carbonate of lime was	8·58 grs.	
That of „ magnesia	1·96 „	

III. This experiment was repeated.

When		35 oz. of water was evaporated
The deposit consisted of—		
Carbonate of lime	5·52 grs.	
„ magnesia	none	
When another		35 „
The deposit consisted of—		
Carbonate of lime	1·27 grs	
„ magnesia	none	
When another		6 „
The deposit consisted of—		
Carbonate of lime	1·62 grs.	
„ magnesia	0·05 „	
And when the remaining		4 „
		80 „
The residue consisted of—		
Carbonate of lime	0·52 grs.	
„ magnesia	3·86 „	
The total quantity of—		
Carbonate of lime was	8·93 grs.	
„ magnesia	3·91 „	

It follows from these experiments, II and III, that in the evaporation of water, carbonate of lime is deposited first, and then carbonate of magnesia. In experiment II traces of carbonate of magnesia were mixed with the carbonate of lime deposited; but in III the deposition of carbonate of magnesia did not commence until $\frac{7}{8}$ of the water had evaporated. Perhaps this difference is owing to inequality of temperature during the evaporation, and also to the fact that in III a wide vessel was used. The reason why a larger quantity of carbonate of magnesia was obtained in the latter than in the former experiment is, that the carbonate of magnesia deposited with the carbonate of lime was not estimated.

It follows, also, from these experiments, that the production of a double carbonate of lime and magnesia cannot take place to any considerable extent, if at all, by the evaporation of water similar to the above, and under analogous conditions. In evaporation at the ordinary temperature, also, the quantity of water evaporated before deposition takes place must be very considerably greater than when the evaporation takes place at a higher temperature.

The inferences drawn from the difference in solubility between the carbonates of lime and of magnesia, in carbonic acid water, correspond with the results of the above experiment.

An idea may, therefore, be formed of what would take place when stagnant water similar to the above well water evaporates to dryness. The lower layer of the deposit that would thus be formed would consist of carbonate of lime, and the upper layer of carbonate of magnesia. The former might contain traces of magnesia, and between the two layers there might be a small quantity of dolomite produced.

It cannot be assumed that bitter-spar is always altered calc-spar; if the greater part of this mineral has originated directly from water, and if this is also the case as regards some dolomites, the production of these minerals must have taken place under special conditions that are still unknown.

The carbonates of lime and magnesia present in water have been called bicarbonates, because it was supposed they had a composition similar to that of the bicarbonates of soda, etc. Since these bicarbonates of the earths are unknown in the solid state, there has been no attempt at their direct analysis. Still, for geological inquiries it is very desirable that the quantity of carbonic acid requisite for dissolving carbonate of lime should be estimated.

For this purpose 1000 grs.* of artificially-prepared solution of carbonate of lime in carbonic acid water was heated in a retort until it began to become turbid, which took place at 212° F. The retort was then immediately removed from the fire, the neck dipped into a vessel filled with lime water, the retort again heated, and the liquid boiled until no more gas was given off. The remaining solution was then evaporated to dryness, and left 0·59 grs. of carbonate of lime. The precipitate of carbonate of lime in the lime water amounted to 0·3 grs., consequently, the proportion of the carbonic acid in the carbonate of lime to that requisite for the solution of carbonate of lime is very nearly as 1 : 0·5. This corresponds with the composition of a sesquicarbonate; and hence it would appear that the solution of carbonate of lime in carbonic acid is a sesquicarbonate like the sesquicarbonates of soda, potash, etc.

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* Much larger quantities of the solution were operated upon, and the results were reduced to 1,000 parts.

A solution of carbonate of magnesia in carbonic acid water was operated upon in like manner. It continued to boil for some time before it became turbid, and was reduced in weight 178 grs. After evaporation to dryness there remained 0·353 grs. carbonate of magnesia, corresponding to 0·182 carbonic acid. The precipitate of carbonate of lime in the lime water amounted to 0·308 grs., corresponding to 0·135 grs. carbonic acid. Consequently, the proportion of the carbonic acid in the carbonate of magnesia to that requisite for its solution, was as 1 : 0·74. According to this the carbonate of magnesia would not be either a sesquicarbonate or a bicarbonate. It is, however, very difficult to determine the moment when the liquid becomes turbid, and this varies according to the amount of carbonate of magnesia in solution. Hence it is probable that the carbonate in solution is, as in the case of lime, a sesquicarbonate.

The maximum amount of carbonate of lime dissolved by water saturated with carbonic acid, is 0·1 per cent.* To dissolve this quantity, therefore, 0·022 per cent. of carbonic acid would be requisite. So small a quantity of carbonic acid as that in meteoric water would, therefore, suffice for the production of a saturated solution of carbonate of lime. Since water saturated with carbonic acid, under the ordinary atmospheric pressure, contains nearly an equal volume of the gas, such a solution would contain about 0·2 per cent. by weight, or ten times as much as is requisite for the solution of carbonate of lime to saturation. Therefore, water containing only one-tenth as much carbonic acid as a saturated solution, can dissolve as much carbonate of lime as water saturated with carbonic acid. Hence, it is evident why fresh water often contains as much carbonate of lime as the water of carbonated springs; and, for this reason, it is not at all necessary to assume that the production of beds of calcareous tuff, or of calc-spar in drusy cavities and in fissures, has been effected by carbonated springs, as is done by many geologists; for fresh water is capable of depositing just as much carbonate of lime as the water of carbonated springs; and that more easily, since there is not so large an excess of carbonic acid to be disengaged in the former case, as in the latter.

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* English edition, ii, 42.

Even water saturated with carbonic acid, under high pressure, cannot dissolve more carbonate of lime than the above-named amount. If this were not the case, the ascending springs would soon fill up their channels, or bring up carbonate of lime suspended in their water; since, as the pressure decreased, the carbonate of lime must be deposited. The hot springs of Carlsbad, which have such a high temperature, that they must be supposed to rise from considerable depths, would, therefore, long since have filled up their channels in this way, or have thrown out, from time to time, carbonate of lime.

A quantity of carbonic acid, so small as that requisite for the solution of carbonate of lime, may be assumed to exist in meteoric water, especially when it is remembered that, in addition to the carbonic acid absorbed from the atmosphere, there is that extracted from the vegetable mould. Since, however, the water of springs is but rarely saturated with carbonate of lime, but generally contains only a small fraction of the possible maximum, it follows that a corresponding fraction of the 0·022 per cent. of carbonic acid would suffice for its solution, and there can be no doubt that the water penetrating through this vegetable mould contains enough for this purpose. Thus, for instance, the water of the Lippe and that of the Alma, contain only about 0·004 per cent. carbonic acid for the solution of the carbonate of lime. But it is this small amount of carbonic acid that gives rise to the sinking of strata and the production of caves, by removing masses of carbonate of lime, that excite our astonishment.

The small amounts of carbonic acid in the atmosphere and in vegetable mould are, therefore, sufficient to produce the alteration of mountains; and the same bubble of carbonic acid is capable of extending its influence indefinitely; for the carbonic acid that is disengaged from water, in consequence of the deposition of the carbonate of lime with which it was combined, is restored to the atmosphere, and again becomes capable of effecting the solution of carbonate of lime. In the same manner as carbonic acid, water is in constant circulation; the drops of water that deposit at one moment a particle of limestone, evaporate; and, falling again as rain, dissolve fresh carbonate of lime, carrying it away and depositing it perhaps hundreds of miles distant. Consequently, the same drop of water may, like the same bubble of carbonic acid, serve for the removal and transfer of enormous masses of carbonate of lime.

It has already* been stated that free carbonic acid exists in sea water; but, until further analyses are made of the air contained in sea water in various latitudes, we must be content with the fact that it is present.

The previously-mentioned† experiment, showing that 17 per cent. of sea water must be evaporated before it becomes turbid, evidently demonstrates the impossibility of deposition of earthy carbonates from water. It is only when an inland lake is dried up completely, when not only the free, but also the half-combined, carbonic acid is separated, that there could be a deposition of carbonate of lime by mere evaporation.

Whether magnesia can be separated from sea water, either as true dolomite or merely mixed with carbonate of lime, by the agency of marine animals, is quite undetermined, and must be left for future investigations to decide. But even if true dolomite could be separated in this way from sea water, it would always be mixed with proportionately large quantities of carbonate of lime. A pure compound of equal equivalents of carbonate of lime and carbonate of magnesia, could not serve for the formation of the shells of marine animals, and, therefore, there is little probability that dolomite is produced directly as a sediment in the ocean.

Water, saturated with carbonic acid, extracts, even from a compound containing more carbonate of magnesia than carbonate of lime, the latter in larger amount than the former. Therefore, while carbonated water extracts from a chemical compound of the two carbonates, more carbonate of lime than carbonate of magnesia, it extracts from a mere mixture of the two carbonates more carbonate of magnesia than carbonate of lime. This difference can only be owing to the tendency to the production of a double salt, for this tendency can be exercised only when the two carbonates are already combined, not when they are merely mixed, in which latter case, there would be no reproduction of dolomite.

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* English edition, i, 116.

† Ibid., i, 107.

It is to this tendency to the production of double salts that we must ascribe the circumstance, that when water containing carbonate of magnesia converts limestone into dolomite, the neutral carbonate of magnesia eliminated combines with the carbonate of lime, producing dolomite, while carbonate of lime is removed by the water that brought carbonate of magnesia.

There can scarcely be any more decisive proof that, in the conversion of limestone into dolomite, large quantities of water have penetrated the rock, than the fact that the calcareous shells in the latter rock have been destroyed, while they are preserved in the limestone. Just as water removes the carbonate of lime from shells, and even the carbonate of lime impressions in limestone, it may also have dissolved the mass of the rock, and thus have facilitated the alteration, whether it took place by the substitution of carbonate of magnesia for carbonate of lime, or by the mere abstraction of carbonate of lime. The carbonate of lime constituting the calc-spar rhombohedrons in the dolomite at the Kahlenberg, near Echte,* can only have been the product of such extraction or substitution. The presence of silica in those fossil remains shows that the water also contained silica, and its extraction from the rock agrees with the usually small amount of silica in dolomite pointed out by Nauck.

It has already been remarked that, although there is not any known case of the displacement of any mineral by calc-spar, a great number of minerals are pseudomorphous after calc-spar, the carbonate of lime being the precipitant of the substances of which those minerals consist.† The evidence of the production of quartz pseudomorphs after calc-spar in the wet way has also been stated. The pseudomorphous quartz after calc-spar, described by Blum as occurring in the Teufelsgrund mine in the Münster valley, is interesting, in connection with the conversion of calc-spar into bitter-spar. In most instances, the points of the pseudomorphs consist of bitter-spar, while the remainder consists of quartz. In one instance, there are remains of calc-spar under the very thin crust of bitter-spar. Blum considers that, in the first instance, hollow pseudomorphs of bitter-spar after calc-spar were produced, and that then the bitter-spar was displaced by quartz. Consequently, water containing carbonate of magnesia effected the first alteration; and, subsequently, water containing silica—perhaps the same water, the magnesia of which was passive, because the carbonate of lime had been removed—penetrated the hollow pseudomorphs, displacing the bitter-spar substance, chiefly at the places where it was in contact with the rock, and not at all at the points of the pseudomorphs. It is worth noticing that bitter-spar acts as the precipitant of silica, and that after it has been removed, the deposition of silica ceases.* This shows that silica may be deposited from water with evaporation.

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* See ante, p. 26.

† English edition, i, 21-23, and 39.

‡ Ibid., ii, 479.

Carbonate of magnesia is decidedly more soluble in carbonic acid water than carbonate of lime, consequently, it might be expected that it would be displaced, not only by the minerals that displace carbonate of lime, but also by carbonate of lime itself. But no pseudomorphs after magnesite are known, as yet, and it is uncertain whether this can be ascribed to the rarity of this mineral, or to the circumstance that its occurrence in rocks—chloritic and talcose slates and serpentine—and not upon lodes or in cavities, is not favourable to the production of pseudomorphs.

The conversion of calc-spar into bitter-spar, which is actually proved by the occurrence of pseudomorphs, seems to be an exception to the generally greater solubility of the displaced mineral, than of that by which it is displaced. At the same time, however, it must not be forgotten that the substitution of carbonate of magnesia for carbonate of lime is only partial, and that it may be facilitated by that tendency to the formation of double salts which is characteristic of magnesia.

Bitter-spar—the double salt produced by this substitution—presents the same kind of relations as calc-spar to other minerals; for calc-spar, brown iron-ore, pyrolusite, and silicate of zinc, displace both calc-spar and bitter-spar. The pseudomorphs are in both cases more or less hollow, which shows that the displaced mineral was more copiously dissolved than that by which it was replaced. The production of cells by the displacing mineral, in consequence of the penetration of water along the planes of cleavage, is presented by both calc-spar and bitter-spar. Altogether, there is not only a very close analogy between all the displacement pseudomorphs after calc-spar and bitter-spar; but, also, such a resemblance between the two series of pseudomorphs, that their production in like manner, from dissimilar material, is unquestionable.

Several pseudomorphs after calc-spar, such, for instance, as those of peroxide of iron, iron pyrites, malachite, etc., are without any analogs after bitter-spar. On the other hand, pseudomorphous steatite after calc-spar, corresponding with steatite after bitter-spar, has but recently been observed.*

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* English edition, ii, 480; Pseudomorphosen, p. 237; Nachtrag, p. 136.

If the displacement pseudomorphs of iron-spar after calc-spar and after bitter-spar were not known, there would not be any more reason for doubting the possibility of their production; for the chief conditions, the presence of carbonate of iron in water, and its inferior solubility to carbonate of lime or carbonate of magnesia, are known to exist. In consequence of this difference of solubility, the pseudomorphs must be hollow.†

Reference has already been made to sedimentary masses in which mechanical deposits are associated with deposits produced by organic action. Some time since, Van der Marck analysed some of the rocks belonging to the transition rocks of Westphalia, grauwacke, siliceous slate, and several kinds of limestone. The former contained carbonates, and, therefore, probably originated by mechanical deposition and organic action combined. In these rocks, as in limestone, the amount of carbonate of iron is as much as 15·9 per cent., and there are generally traces of carbonate of magnesia present. In the siliceous slate there is 9 per cent. carbonate of iron, only 2·5 carbonate of lime, and 0·7 per cent. carbonate of magnesia. In the Adolphskoi valley, in the Ural, there are some black limestone strata which, according to Göbel, contain from 3 to 3·5 per cent. carbonate of iron, and from 1·25 to 4 per cent. carbonate of magnesia. The insoluble residue amounts to from 4 to 40 per cent., showing that there was mechanical deposition while the carbonate of lime was separated by organic action. A black dolomite from the same place is particularly interesting, because it constitutes the basis of the auriferous sand containing diamonds. This dolomite also contains 7·5 per cent. insoluble residue, which seems to show that it has been produced in the same way as the limestone.‡

It would be difficult to account for the production of such quantities of carbonate of iron from sea water. Previous analyses did not indicate the presence of this substance at all in sea water. I have found, by evaporating several pounds of sea water from the German Ocean, that the amount of carbonate of iron is 0·0005 per cent. It is easy to say that there was a greater amount of carbonate of iron in sea water at the time the transition rocks were deposited, than at the present time; but it would be difficult to support this statement. Even if we could assume that the amount of this substance was as great in sea water at that time, as it is in the most ferruginous spring water, the difficulty of accounting for its deposition would not be in any degree lessened. This difficulty is much greater than in the case of carbonate of lime, because the deposition of the latter does not involve exclusion of atmospheric air.

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* N. Jahrb. für Mineral., etc., 1848, p. 397.

† Blum, Die Pseudomorph., etc., pp. 304 and 305.

‡ G. Rose, Reise nach dem Ural, i, 368.

The presence of iron in the shells of marine animals has already been referred to* and its origin explained. It is certain that the carbonate of lime was not displaced by hydrated peroxide of iron, but by carbonate of iron which was afterwards converted into hydrated peroxide. Blum† describes bivalves consisting entirely of sparry hematite, from the lower lias, and compares them with the pseudomorphs of peroxide of iron after calc-spar. In this case, also, the carbonate of lime was displaced by carbonate of iron which was afterwards peroxidized. The pseudomorphous red oxide of iron after iron-spar, furnishes evidence of such alteration.‡

Although it is very probable that the substitution of carbonate of iron for carbonate of lime in these fossil remains was not effected in the sea, but in the rocks where they are imbedded by the water permeating them, still it cannot be questioned that the carbonate of iron in sea water may produce the same effect.

Considering these, and other phenomena described subsequently, we must conclude that not only carbonate of lime and carbonate of magnesia are deposited by organic action, but that carbonate of iron is also separated from solution by the same means, and that both carbonate of magnesia and carbonate of iron can displace carbonate of lime. The latter change must have taken place where, as in the above-mentioned siliceous slate, the carbonate of iron amounts to more than twice as much as the carbonate of lime.

The above-mentioned circumstances relating to the deposition of carbonates from water, are fully confirmed by the phenomena presented by springs. The Carlsbad sprudelstone does not contain a trace of carbonate of magnesia, although the hot water from which it is deposited contains three-fifths as much carbonate of magnesia as carbonate of lime. Therefore, by the evaporation of the water, carbonate of lime only is deposited, and that, perhaps, but partially. But there is not a sufficient evaporation of water for the deposition of carbonate of magnesia to commence, so that the water discharged by the springs flows with the whole of its magnesia into the Tepel. Daubeny* states that the water of the warm springs at Torre del'Annunziata deposits carbonate of magnesia; and, in that case, it must stagnate much longer than the water of the Carlsbad springs, and cannot contain much, if any, carbonate of lime. The deposits from the water of cold springs generally do not contain any carbonate of magnesia, or, proportionately to carbonate of lime, only very minute quantities. Moreover, in drusy cavities containing calcareous deposits, there are only mere traces of carbonate of magnesia.

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* English edition, i, 198. † Ibid., p. 802.

‡ Blum, Die Pseudomorph., etc., p. 188; Nachtrag, p. 110.

Forchhammer's observations† have shown that infusoria and other marine animals contain magnesia, but the quantity thus separated from sea water cannot be equivalent to that carried into the ocean by rivers.

The decomposition of silicate of lime by its reaction with carbonate of magnesia,‡ has already been pointed out as a means of consuming the carbonate of magnesia continually carried into the ocean by rivers. The quantity of carbonate of magnesia thus carried into the ocean by the Rhine, in the course of twenty-four hours, is 4,621,956 pounds. If the whole of this were consumed in the production of dolomite, it would yield 10,087,202 pounds, consisting of equal equivalents of the carbonates of lime and magnesia. This quantity would be equal to a mass 229 at each side, and a foot high. In a year, therefore, a mass of this area and 365 feet high would be formed. This illustration will suffice to show that the carbonate of magnesia conveyed into the ocean by rivers is adequate for the production of enormous masses of dolomite.

Even if this magnesia is partly consumed in the production of steatite, etc., there would still be no difficulty in accounting for the conversion of the limestone strata into dolomite by the action of carbonate of magnesia, sea water, and other water.

Consequently, the production of dolomite, steatite, chlorite and serpentine, appears as the necessary means of disposing of the carbonate of magnesia continually extracted from rocks by water. The production of these minerals constituting large mountain masses is the final result of the metamorphic processes to which magnesian compounds are subject.

Silliman's observations as to the amount of carbonate of magnesia in coralline limestone, furnish still further evidence that there is a substitution of carbonate of magnesia for carbonate of lime.

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* N. Jahrb. für Mineral., etc., 1843, p. 852.

† English edition, i, 183.

‡ Ibid., i, 198.

It has already* been pointed out, that the amount of carbonate of magnesia in a limestone adjoining greenstone dykes had been diminished to the extent of 17 or 18 per cent. Coquand,† on the other hand, gives analyses of four specimens of a fossiliferous shelly limestone which contains magnesia when it is coated with basalt.

	I. Imbedded in the basalt.	II. 1 metre distant from I.	III. 2 metres distant from I.	IV. Limestone with *terebrat vulg.*
Carbonate of lime	57·0	68·0	83·7	92·4
" magnesia	39·6	27·9	9·5	..
Peroxide of iron	0·8	1·0	2·1	3·2
Clay	2·0	2·5	4·0	3·8
Water	0·5	0·6	0·7	0·6
	99·9	100·0	100·0	100·0

Coquand is of opinion that this rock was not melted, because the fossil remains have preserved their external form, but that since they are altered in texture, it had been in some way softened, and that the magnesia was introduced by cementation. In offering this account of the source of the magnesia, it is not stated what became of the silica with which the magnesia was combined.

The fact that the limestone in contact with basalt has been converted into dolomite, is extremely interesting; but the only way in which the fact can be explained is, that the carbonic acid of surface water decomposed the silicate of magnesia in the basalt, and that the carbonate of magnesia was substituted for carbonate of lime in the limestone. It is evident from the diminution of peroxide of iron and of insoluble residue, that other processes of alteration took place in the limestone. But this shows that the conversion of limestone into dolomite is attended with a separation and removal of foreign admixtures, which is the reason of the great purity of granular and crystalline dolomite.

These circumstances differ somewhat from those observed in the conversion of sedimentary limestone into granular limestone. The granular limestone previously referred to,‡ is more or less impure, with the exception of those at Auerbach, Carrara, and Schlanders, in the Tyrol. Consequently, in the conversion of limestone into dolomite, the separation of foreign admixtures takes place to a greater extent than in the conversion of limestone into granular limestone. The material which underwent alteration was often the same in both cases, for at many places, at St. Gotthard, Carrara, and in the Pyrenees, dolomite is constantly associated with granular limestone. In such instances the dissimilar result can only be ascribed to the character of the process of alteration. In the conversion of limestone into dolomite, nearly one-half of the mass is removed and replaced by carbonate of magnesia; and, in the course of such an extensive alteration, probably all the substances that do not belong to the new crystalline product would be removed, together with the carbonate of lime. In the conversion of sedimentary limestone into granular limestone, however, there is no interchange of constituents; the alteration consists merely in the crystallization of the amorphous carbonate of lime; and, since there is no removal of substance, granular limestone does not present the cavities and interstices that are characteristic of dolomite. But, in like manner, as we find in granular limestone a number of other minerals,* so, in dolomite, we not unfrequently find mica, talc, grammatite, and quartz which, like the minerals in granular limestone, are the accessory products of the metamorphic processes by which, in one case, granular limestone, and in the other, dolomite are produced.

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* See ante, p. 145. † N. Jahrb., 1843, p. 850. ‡ See ante, p. 143.

The remarkable deposits of iron ore at Vicdessos and Canigou, described by Coquand, lie in the midst of very dolomitic limestone, and are, most probably, nothing more than accessory products of the conversion of the limestone into dolomite.

He states that in the gold mine La Gardette, the auriferous quartz extends from out of the gneiss into the overlying lias. The lias limestone, which constitutes the saalbands of the lode, is converted into black dolomite, and contains auriferous galena; but, at a distance of a few centimetres, it is quite free from magnesia. However, the same kind of auriferous galena and rhombohedric crystals of dolomite form druses in the quartz that is situated in the gneiss.

This production of dolomite in contact with a lode that has decidedly been filled by deposition from water, is very interesting; for, in this instance, the alteration cannot have taken place in any other way, than by interchange between the carbonate of lime in the lias limestone, and the carbonate of magnesia in water. There is, probably, no doubt that the same water conveyed carbonate of magnesia, silica, and galena; depositing these substances partly in the lode, and partly in the adjoining rock.

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* See ante, p. 140.

Naumann,* in speaking of this dolomite, remarks that since this quartz lode has certainly been produced by deposition from water, the conversion of the lias limestone may be ascribed to the same cause.

It is stated by v. Bibra, that the marly layers of a few inches thickness, which alternate with the hard strata of shelly limestone from two to three feet thick, at Sennfeld in Franconia, sometimes contain a very considerable amount of carbonate of magnesia; in one instance, as much as 44·8 per cent., while the carbonate of lime amounted to only 41·1 per cent. The shelly limestone strata at Karlstadt and at Hirschfeld, near Wippfeld, in Franconia, contains such marly layers in which there is from 12 to 18·4 per cent. of carbonate of magnesia.

Such layers, alternating with limestone strata, cannot have originated in a different way to the latter; they cannot have been produced by the evaporation of sea water and drying up of the residue, so that the whole of the carbonate of magnesia in the sea water could have been deposited. It seems very difficult to account for the formation of these marly layers containing such a large amount of magnesia, because the limestone with which they are associated contains on the average only 1·5 per cent. of carbonate of magnesia. It is difficult to perceive how the conditions prevailing in the ocean during the deposition of these strata, could be so much altered for comparatively short periods, as to give rise to the deposition of these thin marly layers, that, after the deposition of tolerably pure limestone, there should be a deposition of material containing such a large amount of magnesia. The fossil remains, chiefly of fish, occur principally in the hard layers of limestone, but some of the thicker marly layers contain fossil mollusca. Altered conditions of animal life in the ocean appear, therefore, to have taken place during the deposition of these different layers; and this is not opposed to the opinion, that they have been produced by organic action.

In addition to the numerous instances that have been brought forward to show that rocks, whether sedimentary or not sedimentary massive rocks, cannot be regarded as having been originally produced in the state which they now present, we have the occurrence of marine deposits containing large amounts of carbonate of magnesia.

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* Lehrbuch der Geognosie, i, 803.

So far as we are able to judge at the present time, the only explanation that can be given of this fact is, that the considerable amount of magnesia is due either to the substitution of carbonate of magnesia, dissolved in water, for part of the carbonate of lime in the rock, or to the solution and removal of carbonate of lime in much greater proportion than carbonate of magnesia. In the first case, both the mass and volume of the marly layers would have been but very little altered, but in the latter case both would have been very considerably reduced. It could not be expected that in these extremely thin layers any cavities could be produced, especially as the extraction is such a slow process that the overlying strata would sink as it went on without being perceptibly altered in their position. Probably the thinness of these marly layers is an indication of their origin by extraction rather than by substitution, but with regard to this there are many points to be cleared up. The reason why these marly layers only have undergone alteration, and not the layers of hard limestone, may be the more retentive character of the former for water. According to Dana, there are in America many compact limestones, containing from 30 to 40 per cent. of carbonate of magnesia. In the departments Bouches-du-Rhone, Var, and Basses-Alpes, the intermediate portion of the neocomien strata consists entirely of granular dolomite, the stratification of which is continuous with that of the other strata, as is very distinctly shown on a gigantic scale at the range of mountains named l'Etoile and other places.*

There are, also, instances in which fresh-water limestone contains much magnesia. Leube† showed that a compact, cretaceous rock at Dächengen, near Ulm, associated with the beds of fresh-water limestone, has exactly the composition of dolomite. The calcareous sinter occurring in the vicinity of Tilsit is likewise a kind of dolomite. Knapp‡ found from 38 to 49·6 per cent. of carbonate of magnesia in a fresh-water limestone from the brown coal series at Rödgen, near Geissen.

From what has been already stated, it will be evident that such dolomitic strata cannot have originated from the water of springs even when evaporated to dryness, for in that case it would

* Coquand, n. Jahrb. für Min., 1843, p. 851.

† N. Jahrb. für Min., 1840, p. 370.

‡ Liebig and Kopp's Jahresb., 1847 and 1848, p. 1298.

be impossible to account for the large amount of carbonate of magnesia in proportion to carbonate of lime.

In fissures and cavities in rocks, on the contrary, when water gradually evaporates on their surfaces, the deposition of substances containing large amounts of carbonate of magnesia might be expected. Karsten* found such deposits in fissures of the gypsum near Lüneberg, Segeberg, and Lübtheen. His analyses of several deposits of this kind in fissures show that the relative proportions of the carbonates vary considerably, the carbonate of magnesia being from 4 to 68 per cent. Since cold acetic acid, and even dilute hydrochloric acid, extracted the whole of the lime, leaving pure carbonate of magnesia, Karsten infers that the two carbonates were not combined, but that they had been separately deposited in a crystalline state from solution.

It is singular that in this instance bitter-spar was not produced. The carbonates, however, are mixed with from 5 to 50 per cent. of ferruginous silicate of alumina, and it is probable that the presence of this substance hindered the crystallization of the double carbonate.

Three specimens of the shelly limestone, near Lüneberg, gave the following results on analysis by Karsten:—

Portion insoluble in acids, consisting chiefly of pure quartz sand	11·79	10·05	10·33
Alumina with some peroxide of iron ..	1·96	2·48	1·01
Carbonate of lime	84·60	81·56	88·32
„ magnesia	1·41	5·69	0·17
Bitumen	0·24	0·22	0·17
	100·00	100·00	100·00

Two specimens of dolomite, originating from the alteration of this limestone, had the following composition:—

	I.	II.
Silicate of alumina	1·07	0·64
Alumina containing some peroxide of iron	12·38	19·30
Carbonate of lime	46·81	43·26
„ magnesia	37·50	34·50
„ iron	2·24	2·30
	100·00	100·00

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* Archiv., xxii, 589.

I. Presented a compact, fine-grained, earthy fracture.

II. Compact argillaceous dolomite.

Adding the carbonate of iron to the carbonate of magnesia, the proportion between these carbonates and the carbonate of lime is nearly that of equal equivalents, the same as in pure dolomite. But since both kinds were compact, and earthy or argillaceous, it may be concluded that the admixtures hindered the crystalline development and production of bitter-spar.

Karsten found that the carbonate of magnesia in the above limestones could not be separated even by the weakest hydrochloric acid, but was always dissolved together with the carbonate of lime. It was only by very slow solution with very weak cold acetic acid, that the solution of carbonate of magnesia could be to any considerable extent prevented. And then the residue is not pure carbonate of magnesia, as in the case of the deposits in fissures of gypsum, but true dolomite. Consequently, this limestone contains very varying amounts of dolomite.

The total absence of bitumen in this dolomite is regarded by Karsten as a proof that the limestone in the course of its alteration has been exposed to intense and long-continued heat. But in opposition to this it may be remarked, that the analyses show that there is no carbonate of iron in the limestone, although it is present in the dolomite. Therefore, the carbonate of iron has either been produced by the reduction of peroxide of iron in the limestone, or it has been introduced during the alteration. In the former case a reducing agent would have been necessary; the bitumen would have served this purpose, and being converted at the same time into carbonic acid and water, would have disappeared.

All observed phenomena are in favour of the conversion of limestone into dolomite. At the Lugan lake, the gradual transition of regular limestone strata into dolomite may be particularly well traced. The limestone is at first quite free from magnesia, then traversed by small veins of dolomite, then presenting crystals of bitter-spar in cavities, then much fissured, and lastly, where all traces of stratification are obliterated, the mass appears as perfect massive dolomite.* In the islands of Man and Skye limestone strata are as intimately connected with the masses of dolomite as with the granular limestone.† Near Sinnatengrün there is a perpendicular tilted stratum of limestone, surrounded completely with dolomite.[*] Limestone was observed by v. Dechen in North Wales alternating so frequently with dolomite that both may be observed in one specimen. Karsten,[†] found the opposite ends of one piece of dolomite of the following different composition—

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* Daubeny on Volcanoes, 2nd ed., p. 150.

† De la Beche, Geognosie von v. Dechen, p. 575.

Carbonate of lime	63·27	57·75
„ magnesia	35·97	41·32

Such unmistakeable instances of the transition of limestone into dolomite can only be ascribed to the conversion of one into the other.

Much light has been thrown upon the origin and production of dolomite by v. Klipstein's[‡] careful examination of the dolomite in the Lahn district, and that in the jurassic rocks on the Danube.[§] In both places the phenomena are analogous, but they are more distinct and characteristic in the Lahn district.

Almost all the dolomite in this locality is confined within the extent of the transition limestone, where it occurs in a variety of forms. Sometimes it traverses the limestone as unmistakeable dykes, sometimes it is imbedded as nests, and sometimes as large irregular masses. Dyke-shaped masses of dolomite, generally in a vertical position, were also observed in limestone by v. Strombeck[||] and Abich[¶] at the Kahlen-Berg, near Echte, between Göttingen and Brunswick, and in the valley of Tramonte. At several places near the Lahn the dolomite intersects the limestone strata, and then spreads out over them like a roof six or eight feet thick. In some of these dykes the dolomite is very much decomposed, and presents a striking contrast with the unaltered limestone adjoining. The decomposition is generally so far advanced that the dolomite easily breaks down when touched, into a heap of small granules, which by the aid of the microscope appear as rhombohedrons of bitter-spar chiefly.[**] In other of the dykes the dolomite is almost everywhere unaltered, or only somewhat decomposed where it covers the limestone traversed by the dykes. The decomposed dolomite is tolerably distinct from the adjoining rock; but the unaltered dolomite is blended with the limestone, branching into it, or appearing as imbedded granules and masses. Close to the line of junction, are imbedded masses of a very fine-grained rock containing but little magnesia, which, at the centre especially, are not distinguishable from the limestone, and even present the same fossils—*cyalocrinites pinnatus*—that occur in it.

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[*] Nauck, Op. cit., p. 134.

[†] Archiv., xvii, 65.

[‡] Karsten u. v. Dechen's Archiv. für Min., etc., xvii, 205.

[§] Ibid., xvi, 2.

[||] Ibid., viii, 488.

[¶] Op. cit. p. 111.

[**] L. v. Buch refers to this decomposition of dolomite. As the small crystals of which it consists are in contact only at a few points, the coherence of the mass is readily overcome, and it is decomposed into granules resembling sand.

While the dyke-shaped masses of dolomite are traversed by vertical fissures several feet wide, the limestone does not present anything remarkable in this respect. Such a fissure was traced to a considerable depth, and appeared to terminate in a cave.* Numerous lateral fissures extend from these vertical fissures, to such an extent in the dolomite overlying the limestone, that it appears separated into small angular fragments.

At one place a number of veins of dolomite extend downwards through the limestone from a mass of dolomite overlying the limestone. These veins become narrower as they extend downwards, and continue as narrow cracks. Some of these cracks are filled either with impure wad, or with decomposed dolomite highly impregnated with manganese. The upper portion of this mass of dolomite enclosed several large nests of limestone. At one place, on the contrary, there are dolomite nests in the limestone, and here the dolomite veins contain large fragments of limestone imbedded in their mass.

The dolomite of this district contains varying amounts of manganese, as is shown by its colour. This manganiferous dolomite is characterized by frequent cavities, sometimes several inches diameter, the sides of which are lined with crystals of bitter-spar and calc-spar, often coated with very thin crusts of wad or pyrolusite, both of which minerals, and especially the latter, also occur pure in cavities. The occurrence of manganese compounds in this district is limited to the dolomite, and is highly interesting.

In the Linder Mark there is a large shallow basin in the transition rocks, filled with plastic clay, resting entirely or chiefly upon dolomite, and containing a rich deposit of manganese ores. This dolomite is particularly characterized by the number of bitter-spar rhombohedrons it contains. They not only line the interior of the cavities, but also cover most of the fissures, frequently extending deep into the mass of the rock. This dolomite is, also, full of pyrolusite and wad, sometimes disseminated through it, sometimes lining cavities, and sometimes imbedded as large masses. Between the plastic clay and the dolomite there is a layer of manganese ore a foot thick. Under this layer the dolomite is most highly impregnated with manganese, and the bitter-spar rhombohedron, from which the original substance has been removed, are filled with manganese. The mass of the rock itself is so highly impregnated with manganese that it is scarcely distinguishable from the layer of manganese ore.

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* L. v. Buch mentions, in his description of dolomite, these large vertical fissures as being a characteristic feature of the rock. He says that at Rauhkofel, the descent from the Leisach Alp, on the road to Lienz, is made by steps cut in the rock for a height of 1,200 feet. Geognos. Briefe, 1824, p. 186.

The occurrence of dolomite dykes and nests in limestone,* and of limestone nests in dolomite, present such an intimate blending of a crystalline rock with a compact rock, that it is impossible to suppose they have originated simultaneously as sedimentary deposits, so that by this circumstance again we are led to infer that alteration has taken place.

In Klipstein's memoir the conversion of limestone into dolomite is represented as the effect of magnesian vapours. The manganese ores are, also, supposed to have been sublimed. However, it is not stated how, after these vapours were condensed, the carbonic acid was provided for the carbonate of magnesia, or how the sesquioxide of manganese was converted into binoxide.

It is, morever, a peculiar characteristic of such hypotheses as this, that they are not limited by observed facts, but set them aside; thus Klipstein remarks, that although several of the dolomite dykes do not present, at their lower end, where they branch out, fissures extending downwards, he is not the less convinced that the dolomite was produced by a cause acting from below upwards, and would not be, even if none of the other masses of dolomite presented at their lower extremities cracks extending downwards, because, though a connection with the interior of the earth might not be recognizable at a particular section, it might exist at other places.

I am unable to perceive any other meaning in this remark than that by some kind of communication like a syphon, the vapour rising through one channel has been forced down into others that are contracted as they extend downwards. This assumption is very improbable, independently of the difficulty in perceiving how the magnesia could be vaporized. In opposition to this view, I am disposed to consider that the production of dolomite was effected by water permeating the rock from above downwards. The fact that the limestone has been converted into dolomite at some places and not at others, is not in any degree more explicable by one hypothesis than by the other. If the cause of conversion acted from below, there would have been as much necessity of channels as if it acted downwards; there must, also, have been lateral channels of communication in the former case, while in the latter case they need only have been in the same direction as the dolomite veins are found to be. Moreover, if the conversion of the limestone into dolomite is regarded as having been effected by water permeating the rock, it is not even necessary to suppose that there were any actually open channels, for if the limestone were more easily permeable at some places than at others, the production of dolomite would take place there. It would be superfluous to bring forward evidence that rocks are more easily penetrated by water at some places than at others; but the fact that the dolomite in some of the above-mentioned dykes is quite decomposed, while that in others is quite unaltered, shows that this is the case as regards this dolomite.

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* Forchammer, op. cit., also found lumps of dolomite in sandy limestone.

The penetration of water to a greater or less extent is very much determined by the configuration of the surface of the rocks. At the hollows it is much greater than at the elevated downs or hills. The greater part of the water falling upon the surface of limestone collects in the funnel-shaped depressions.* When there is a sinking of the surface to such an extent as that near the Pader, which is 150 feet in diameter, the quantity of water that falls upon such an area annually, amounts to 50,000 cubic feet; and this permeates a mass of limestone, the sectional area of which is not, perhaps, one-hundredth of that extent of surface.† If this water dissolves carbonate of lime and leaves dolomite, considerable masses of dolomite might be produced if the amount of carbonate of magnesia in the limestone were large. Dolomite may, however, be produced not only by such a process of extraction, but also by the removal of the dolomitic residue from the upper portions of the strata to lower points, where the limestone may be converted into dolomite by the displacement of carbonate of lime. Thus it may be understood, that all the carbonate of magnesia in the limestone that has been removed from the above funnel-shaped depression has been employed in the production of dolomite, and that in this way masses of dolomite may be produced in the midst of limestone. If, as in the chalk series of the Teutoburg forest, there is a succession of such depressions in the same direction, dykes of dolomite of considerable extent might be produced in the same manner.

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* Gansauge, Poggend. Annal., li, 293, states that at Karst, in the limestone district of Trieste, the effects of heavy showers soon disappear; while, in the Adelsberg caves, the increased dripping of the stalactites shows that it has rained outside.

† Petzholdt, Beitr. zur Geogn. von Tyrol., p. 208, mentions that in the Etsch valley, where the limestone is traversed by vertical fissures, there are considerable heaps of rubbish at the lower ends.

Sinking of strata is caused not only by the caves in limestone rocks, but also by heavy rains when the limestone is covered by a thick layer of broken limestone. This has been observed in the Haargebirge adjoining the Teutoburg forest; and by sinking a shaft from the lowest point of the funnel-shaped depression the cavity into which the crumbled limestone has been carried by the rain-water has been found. In this way the fissures in limestone may be again filled up. Then if water passes less copiously and violently along over these loose masses, these conditions would be extremely favourable for the production of dolomite, partly by the extraction of carbonate of lime, and partly by the substitution of carbonate of magnesia for carbonate of lime. By such alternate mechanical and chemical deposition, fissures in limestone may be eventually filled with dolomite.

It is evident that by such mechanical and chemical action of water, large masses of limestone would eventually be abraded, and that in this way carbonate of magnesia would be continually furnished for the production of dolomite. It may, therefore, be understood, that in places where there are extensive surfaces covered with carbonate of lime, originating from the disintegration of limestone, continuous masses of dolomite might be produced over previously-formed dolomite dykes. This would take place the more readily by mere extraction, because in the loose mass of carbonate of lime each particle would be exposed to the action of water, and because this loose material would continually sink down and form a continuous mass.

The walls of the sunk strata present very wide fissures, generally filled with carbonate of lime; and displacement of the blocks of limestone separated by these fissures. At the centre of the numerous depressions in the mountain limestone of the Illyrian and Dalmatian coasts, the fragments of rock torn from the sides are piled together in a heap. This agrees with the account given by Heim,[*] of the broken and dislocated strata of magnesian limestone near Meiningen.

In reply to the objection which might be made that magnesian limestone, or dolomite, would always occur under such funnel-shaped depressions, if the above view of their formation were correct, I would remark, that even when all the other conditions for the production of dolomite exist, no dolomite can be produced if there is no magnesia in the limestone, or when its amount is very small; and also that, in limestone strata, where such depressions have taken place recently, or are still going on, the conversion of the limestone into dolomite would not be recognizable until after some considerable lapse of time. I am merely of opinion that where masses or dykes of dolomite occur in limestone rocks, there may have been, at some former period, conditions similar to those observed at the present time in limestone districts. We are ignorant of what lies under the depressions that have taken place at very remote periods. However, the caves near Muggendorf are situated in dolomite; and, in this instance, the conjecture that the dolomite would be found to extend to a considerable distance above the roof of these caves, is natural. On the other hand, the numerous caves of the Würtemberg Alps are situated in compact jurassic limestone.[†] Both in the upper and lower strata, they are generally independent of the dolomite, more rarely associated with it.

Schübler mentions several circumstances which he considers render it highly probably that, at least, the first cause of the formation of caves, was not the washing away of the limestone rock. He considers that, in consequence of the drying of the limestone strata elevated above the sea, and of the contraction caused by it, cracks and fissures were produced, separating the horizontal strata transversely from top to bottom. He considers, also, that earthquakes and volcanic eruptions have contributed to the production of fissures.

There can be no doubt that such causes have given rise to the production of fissures, but it is not easy to perceive how caves could be formed in this way. The strata of the jurassic limestone are situated horizontally above one another in several of these caves, but they are fissured vertically; and, in other instances, where the strata are inclined, they are also fissured vertically at some places, forming a large natural vault. The sections of some of the caves in the Würtemberg Alps, show distinctly that the strata have not been disturbed during the formation of the caves; for almost everywhere they are horizontal, and the ends at each side of the caves correspond perfectly. But if violent action had taken place, the strata would have been displaced, for the strata could not have been forced apart as if by a wedge. The fractures of the strata at the interior of the caves, and the large masses of fragments lying upon the floor of the caves have, undoubtedly, originated from the action of water on the rocks. Consequently, there cannot be any other explanation given of the origin of these as well as other caves, than that they have been hollowed out by water. The fissuring of the strata must, of course, have preceded this action, so that the water might penetrate. But the fissuring of rocks is a very general phenomenon and, therefore, it is unnecessary to assume any special cause for the fissures in limestone. There is, however, this difference between limestone and slate, or sandstone strata, that the constituents of the former are soluble in water, and are, therefore, removed either wholly or, for the most part, while the constituents of the latter are but partially soluble, or decomposable, by water. It is for this reason that caves occur, with few exceptions only, in limestone rocks.

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[*] Naumann's Geognosie, i, 800.

[†] Kastner's Archiv., v, 11.

If it is certain that the lofty crags, pyramidal and obelisk-shaped masses of dolomite in the Fassathal, are the remains of the previously-existing limestone mountains, and that their height, at least, represents the former thickness of these strata, it will be evident, by comparing the large spaces between these masses, and the volume of the existing dolomite, that the mass of limestone that has, in the course of time, been removed, is disproportionately greater than that which remains. By such a comparison, the possibility that even a small amount of magnesia in these masses of limestone may have furnished the material for the dolomite becomes intelligible. This possibility would be equally apparent if the spaces between the masses of dolomite were less, and if, at the same time, the height of the original limestone mountains was much greater than that of the highest of these masses of dolomite. It is, indeed, scarcely possible to arrive at any other conclusion, than that these masses of dolomite were produced as dykes or beds in the original limestone strata, and that they were subsequently laid bare by the denudation and removal, by water, of the surrounding portions of limestone that had not been converted into dolomite.

Such processes of destruction and conversion may have been effected either by surface-water, like the depression of strata, or by the action of sea water. In either case, the carbonate of lime removed would have been carried into the ocean; for this is the peculiar characteristic of limestone and other strata consisting of carbonates, that their entire mass, with the exception of iron compounds and a portion of the silicates, is restored in a dissolved state to the ocean; while in the case of other rocks, such as clay-slate, crystalline rocks, etc., only a small portion is carried into the ocean in a state of solution, the greater part being carried away in a state of suspension only.

In the case of carbonates, the passage from the state of solution to the solid state, and again from the solid to the dissolved state, is much more rapid than in the case of any other rocks; the carbonate of lime dissolved to-day may, to-morrow, be converted into the solid state by shell-fish, while the silicate of potash carried into the ocean in solution, or the suspended silicate of alumina may require an incalculable period of time to be converted again into felspar. Since the alteration in the state of aggregation of carbonate of lime takes place in such a short time, the large masses of water requisite for the solution of whole mountains of limestone, cannot be a matter for wonder; for the drop of water which to-day yields its carbonate of lime to a shell-fish, may, by evaporation, be again transferred to the land in a few days, and having become again charged with carbonate of lime, may be again carried into the ocean. A mass of water, equal in weight to a limestone mountain, may, when, by evaporation from the ocean, it is returned to the land 5000 times, and when it dissolves only as much carbonate of lime as is present in the water of the Lippe and the Alme, dissolve away the whole mountain. While the first layers of a coral bank are being deposited, the carbonate of lime, of which the last layers are formed, may be still a constituent of limestone strata.

If, therefore, there are good reasons for holding the opinion that the conversion of limestone into dolomite took place above the ocean, the large masses of water that were requisite for the removal of the carbonate of lime, and the concentration of the carbonate of magnesia, would have been amply supplied in the manner that has been described.

The rent and fissured condition of the dolomite is described by Klipstein as presenting such a striking contrast with the limestone, that this is alone sufficient to suggest the idea of the exercise of force from below. However, he does not state what this force may have been. If it were the explosive force of compressed magnesian vapour that rent the rock, the removal of prismatic masses of limestone could not have been effected in this way. But if by any such means fissures had been produced, it does not appear why they should not have been produced after, as well as before, the evolution of magnesian vapour, when it had again become compressed, for, by the introduction of magnesian vapour the volume and mass of the limestone would have been considerably increased. Karsten,[*] indeed, accounts for this, by assuming that the magnesian vapour displaced vapour of lime; and thus attempts to explain the origin of the extensive masses of pulverulent limestone, and for the fissured condition of the dolomite. The occurrence of dolomite nests imbedded in the limestone, is equally inexplicable according to Klipstein's hypothesis, for it is impossible to perceive how the magnesian vapour could have penetrated through the surrounding mass of limestone without altering it. By the action of water, however, such local alterations may be easily brought about, and numerous illustrations of this fact have been already given.

Grandjean,[†] who examined the dolomite and brown-coal measures in the lower Lahn district, states that the same kind of phenomena are presented there, as at the higher parts of the Lahn examined by Klipstein. Wherever the fissures and cracks of the slightly inclined limestone strata have facilitated the penetration of water, there the production of dolomite appears to have taken place to the greatest extent. The strata which, by their exposed situation, were most liable to this penetration, present the most advanced state of alteration. But, in the lower beds of limestone, there has been but little, if any, production of dolomite. The dolomite, and the partially altered beds of limestone adjoining it, are traversed by numerous cracks, fissures, and cavities; and where the alteration is more advanced, the iron and manganese compounds, to which the colour is due, have been separated. These substances line the walls of fissures in the form of stalactites. A portion of the carbonate of lime has also been deposited in the same manner in cavities, as calc-spar.

At the places where manganese and iron ores are worked, there is a succession of several clay beds, varying in thickness from a few feet to fifteen fathoms; and this is quite analogous to the phenomena presented in the upper Lahn district. Since the alteration of limestone, in consequence of the production of dolomite, may often be traced, even in a hand specimen, from the first stage, to the total conversion into an argillaceous mass, Grandjean infers, that where the level character of the surface facilitates the continuous action of water, the limestone may be ultimately converted into clay.

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[*] Op. cit., p. 571.

[†] Op. cit.

By the analysis of a specimen of transition limestone from Tiefenbach, in this dolomitic district, I found that it consisted of:—

Carbonate of lime	69·90
„ magnesia	2·34
„ iron and manganese ...	8·18
Clay insoluble in acid	20·43
	99·95

The iron was calculated as carbonate, although the greater portion existed in the state of peroxide. Such a limestone would yield, after the extraction of the earthy carbonates by carbonated water, 26·07 per cent. of ferruginous clay, for the greater part of the carbonate of iron would be peroxidized by the oxygen in the water.

According to a section sent to me by Grandjean, the relative situation of the strata in this locality, from above downwards, is as follows:—

1. Clay.
2. Coloured clay.
3. Nodular manganese.
4. Dolomite.
5. Limestone.

The clay beds present depressions which, probably, correspond with the caves in the limestone. The opinion that this clay is the residue left by the washing away of carbonate of lime from the limestone, is rendered more probable by the occurrence of fossil remains in the clay, similar to those in the limestone. The water, charged with carbonate of lime, would have flowed away through the caves. The carbonate of magnesia, carried away at the same time, may, nevertheless, have been consumed in the conversion of limestone into dolomite; and this is the more probable from the fact, that the beds of dolomite are generally only a few feet thick, and overlay the compact unaltered limestone.

Grandjean's opinion that the production of dolomite is effected by the removal of the excess of carbonate of lime from magnesian limestone, is supported by the action of dilute acetic acid upon limestone containing carbonate of magnesia, for if this acid removes only carbonate of lime, this would be still more probably the case with water containing only the small amount of carbonic acid derived from the atmosphere. I have, however, made some experiments in reference to this point.

Two specimens of magnesian limestone from Stadtbergen were found to have the following composition:—

	A.	B.	C.
Carbonate of lime	98·22	84·57	14·01
„ magnesia	1·32	11·54	15·14
Peroxide of iron	0·17	..	..
Silicate of iron	0·51	..	..
Carbonate of iron	..	1·15	56·06
„ manganese	..	..	14·79
Silica and carbon	..	1·36	..
	100·22	98·42	100·00

A. Dirty yellow limestone.

B. Black limestone.

Both these limestones, and sphærosiderite having the composition C, were finely powdered and mixed with water, through which carbonic acid was passed for twenty-four hours. The liquids filtered from the residue were evaporated to dryness, and found to contain—

	A.	B.	C.
Carbonate of lime	2·93	4·29	68·97
„ magnesia	trace	no trace	17·24
„ iron	..	..	13·79
	in 9534 grains	in 6660 grains	100·00

It appears, therefore, that water saturated with carbonic acid does not dissolve out of the limestone more than a mere trace of carbonate of magnesia, even when the amount of this constituent is as much as 11·5 per cent. The action of water containing still less carbonic acid would, probably, be still less also. Hence, it seems unquestionable, that by the action of surface water, or of sea water, upon limestone, the carbonate of magnesia would be concentrated until ultimately dolomite remained.

By such conversion of limestone into dolomite, the mass of the original limestone would be the more reduced in proportion as the amount of carbonate of magnesia was less. Limestone which, like the above, contained only 2·34 per cent. of magnesia, could yield only 5·1 per cent. of dolomite; and if at the same time it contained, like that, 26·07 per cent. ferruginous clay, a rock would be produced which could not be called dolomite. It has already been shown that small amounts of silicates may be removed in the course of the alteration; but it is not probable that such large amounts of clay-slate substance as that existing in this limestone could be completely removed. Consequently, the conversion of limestone into dolomite can only be supposed to take place with limestone free from any large amount of foreign admixtures.

Heim states that the magnesian limestone in the neighbourhood of Meiningen is highly impregnated with calc-spar. Klipstein, Grandjean, and Sandberger, also mention the occurrence of calc-spar in drusy cavities in the dolomite. Volger* speaks of stalactites of carbonate of lime in the caves and fissures in dolomite, and of calcareous tuff at their bottom. Since these observations are in contrast to the occurrence of bitter-spar crystals in the cavities and hollows in the dolomite of the Tyrol, it might be conjectured that the dolomite containing calc-spar druses is still in course of formation, while in that containing bitter-spar druses the conversion is complete.

This question might, probably, be decided by the analyses of the different kinds of dolomite. If that containing calc-spar was found to have a composition corresponding to three equivalents of carbonate of lime to two of carbonate of magnesia,† and if that containing bitter-spar druses had a composition corresponding to equal equivalents of the two carbonates, the above conjecture would be supported; for, in the former case, one-third of the carbonate of lime would have to be removed before the mass would have the normal composition of dolomite. From dolomite of this composition, however, water dissolves not carbonate of lime, but both carbonates in equivalent proportions, depositing them again as bitter-spar having the same composition. It would, also, be interesting to have analyses of the calc-spar occurring in druses of dolomite.

Considering all these circumstances, it appears probable that limestone containing little or no silicates, but rich in magnesia, may be converted into dolomite on the spot, by extraction of the excess of carbonate of lime.

The occurrence of manganese compounds, in connection with the dolomite in the Lahn district, corresponds with the presence of manganese in the transition limestone, and the rich deposits of manganese ores in plastic clay consist, like the latter, of the residue of limestone from which carbonate of lime has been extracted. If this residue had the same composition as that above mentioned,[*] the oxides of iron and manganese would amount to 21·6 per cent. By the action of water containing organic substances on this clay, the oxides of iron and manganese would be reduced and converted into carbonates. Consistent with this view is the fact, that the lower beds of clay are coloured, while the upper ones are not. If this colouration is owing to oxides of iron and manganese, these oxides are present, in part at least, in the lower beds of clay, but have been abstracted from the upper beds by water.

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* Poggend. Annal. lxxiv, 45.

† English edition, ii, 47.

By the action of the oxygen in the water, the carbonate of manganese is converted into pyrolusite, psilomelan, and wad, while the carbonate of iron is converted into iron-ochre and red oxide of iron. These products of alteration occur variously mixed together, but masses of pure pyrolusite also occur, and sometimes these masses are connected by veins of the same substance. Braunite also occurs in the upper part of the plastic clay as bunches, and stalactitic masses that appear eroded and perforated with holes, evidently indicating their origin from descending water. The beds of decomposed manganese ores between the plastic clay and the dolomite, the impregnation of the latter with manganese, and the occurrence of a vein filled with decomposed manganese ore and fragments of dolomite, in a large mass of dolomite, the rock adjoining which is at both sides impregnated with manganese for a considerable distance, are all indicative of this mode of production.

Since pyrolusite, hausmannite, and manganite, occur pseudomorphous after calc-spar,[†] and since Grandjean[‡] has found psilomelan and pyrolusite pseudomorphous after bitter-spar in the manganese mines at Niedertiefenbach, near Limburg, it is very probable that the manganese ores, associated with dolomite, have originated by the displacement of carbonate of lime prior to the production of dolomite, or by the displacement of dolomite itself.

Grandjean is of opinion that the deposits of iron ore near

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[*] See ante, p. 194.

[†] Blum.—Die Pseudomorphosen, p. 258.

[‡] Nachtrag zu den Pseudomorphosen, p. 140.

Dillenburg, Weilburg, in Westphalia, etc., have originated by the displacement of carbonate of lime by ferruginous water. The perfect retention of form presented by the fossil remains, consisting of peroxide of iron, leaves little doubt as to this. These changes, like all others that take place in rocks, did not commence till after the formation of valleys, as may be seen from the fact that the outcrop of these deposits of iron ore consists of unaltered limestone, or that the iron ore gradually tapers off into a bed of greenstone, schalstone, or slate.

Klipstein considers it probable that the manganese with which the above-mentioned dolomite is impregnated, may be disseminated further throughout the fissured and cracked rock, though he is not disinclined to believe there are dykes in the neighbourhood of the dolomite from which the manganese ores are derived. With regard to this opinion, it is only possible to say with Macculloch,* "that which ought to be, is the eternal obstacle to the discovery of that which is." Klipstein himself mentions facts which indicate the nature of the conversion of psilomelan into wad. Thus, for instance, the psilomelan contains 16 per cent. of baryta, while the wad contains only 1·4 per cent. If this alteration has been effected by water, it is very natural to suppose that the water flowed formerly where it now flows; and if it is capable of removing material now, it might have done so as well formerly. Why, therefore, assume the existence of dykes or veins through which the manganese ores, that are decomposed by heat, are supposed to have been protruded from the interior of the earth?

If it is transition limestone that has furnished the material for the production of the manganese ores and of the plastic clay, it will be requisite to ascertain what may have become of the carbonate of lime contained in it. If the limestone had a composition similar to that at Erdbach,† the carbonate of lime would amount to sixty-five times as much as the carbonate of manganese.

In the lower Lahn district, near Dietz, the dolomite begins to be associated with greenstone and schalstone, and it might seem probable that the carbonate of lime extracted from the limestone undergoing alteration, has contributed to the production of the schalstone. But according to the observations of Grandjean, the occurrence of this rock in the vicinity of the dolomite is not calculated to support this view. Here, as at Villmar, thick beds of limestone alternate regularly with the schalstone beds, generally of less thickness. These schalstonè beds contain many of the same kind of fossils as the limestone between them. Near the junction with limestone the fossils are more numerous, and the schalstone texture extends for some distance into the limestone. These facts would seem to show that the schalstone at this place is altered limestone, and has been produced by the partial abstraction of carbonate of lime by water, from the other constituents of the rock.

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* System of Geology, ii, 150.

† See under Schalstone.

From a chemical point of view, this opinion may be to a certain extent supported. Assuming that by the action of water upon transition limestone having the same composition as that at Tiefenbach, 54·06 per cent. of carbonates of lime and magnesia were to be removed, the residue would consist of a mixture of clay and carbonate of lime, resembling somewhat closely the composition of schalstone. By this abstraction of material the thickness of the beds would be reduced to the extent of 54 per cent. By such an alteration the inclined beds of limestone, similar to those at Villmar, would have undergone considerable change of position; and it would have to be ascertained what material had been deposited in the cavities thus produced. Such a formation of schalstone may also be inferred from the geognostic relation of limestone and schalstone pointed out by Stifft and Beyrich, and it may, therefore, be regarded as highly probable.

Grandjean goes still further in this respect; and is of opinion that greenstone, which is so similar to some kinds of schalstone, as well as the slate of the transition series, have originated in like manner. This slate contains the fossils of the adjoining transition limestone, as, for instance, at Baldiunstein; and it passes into schalstone in such a manner that it is impossible to distinguish one from the other. Some kinds of transition limestone pass directly into slate, as, for instance, near Herborn, where beds of very compact carbonaceous limestone crop out as slate strata only a few feet thick.

Moreover, since transition limestone consists of mixtures of carbonates with clay-slate substance, an argillaceous residue would be left when the carbonate of lime was removed. There is a brown layer in the transition limestone at Erdbach, which shows the total abstraction of carbonates. The transition limestone at this place, like the calcareous clay-slate in Westphalia, has originated from mechanical depositions taking place simultaneously with precipitation of carbonate of lime. In the former, the mechanical deposit amounts to 26 and 28·6 per cent. while, in the latter, the carbonates amount to 26·6 and 27·5 per cent.

If the conversion of transition limestone, containing argillaceous admixtures, into clay-slate, by the extraction of carbonates does take place, it is quite possible that greenstone may be produced from such limestone, in like manner, since, as will subsequently be shown, the conversion of slate into greenstone is very probable.

All the possible and probable alterations of the transition limestone in the above-mentioned districts, and its conversion into schalstone, clay-slate, greenstone, and clay, as well as the production of red hematite and manganese ores, imply the removal of large masses of carbonate of lime. But little of this carbonate is met with in veins; the greater part has been carried into the ocean where limestone is produced, and where it furnished the material for the production of limestone. The conversion of limestone into dolomite is directly connected with the above series of metamorphic processes. Whether this change takes place by the substitution of carbonate of magnesia for carbonate of lime, or whether it takes place by mere abstraction of carbonate of lime, there is always a removal of carbonate of lime by water. Consequently, the most diverse geological phenomena which have, hitherto, been ascribed to the influence of contact, to eruption, or sublimation, may be all reduced to one simple process, which goes on continuously before our eyes, namely, the extraction of carbonate of lime from limestone. A comparison of the analyses of the original rocks, with those of the products of their alteration, shows what enormous masses of carbonate of lime have been removed.

The removal of such masses of carbonate of lime presupposes a very long period of time. This is also indicated by the occurrence of plastic clay, thick beds of sand and quartz pebbles, which partially cover the limestone projecting from the grauwacke, and surrounding the dolomite near Kleinlinden, and Lützenlinden, for the sand and quartz pebbles originate from grauwacke that has been removed together with the limestone.

The opinion that dolomite has been produced by alteration of limestone has been opposed on several grounds. Thus Wissmann* points out that the dolomite in the Tyrol occurs together with limestone in the melaphyr; that the dolomite is stratified for a considerable distance, conformably with underlying layers of limestone, marl that is sometimes dolomitic, shale, and sandstone; and that, for distances of some miles, there is not any melaphyr in contact with the dolomite. He considers that it is impossible to account for the facts that limestone, entirely surrounded by melaphyr, is not at all converted into dolomite, while large mountain masses in the vicinity, such as the Schlern and the Langkopel, consist entirely of dolomite; and that the limestone underneath the dolomite should be, for miles, unaltered, while the very much larger masses overlying them, should be entirely converted into dolomite. Hence, Wissmann infers that the dolomite of the Fassathal cannot have originated from limestone, but must have been deposited in the first instance as it now appears.

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* Beiträge zur Geognosie und Petrefactenkunde des Sudöstlichen Tyrols, Bayreuth, 1841, p. 10.

Some importance attaches to Wissmann's observation, that melaphyr occurs with limestone and dolomite fragments imbedded in it, and that fragments of melaphyr are imbedded in the dolomite in such a manner that they must have existed before the dolomite became solid. He considers that these circumstances indicate, to some extent, a simultaneous production of these rocks, and I would add, that they prove still more forcibly that there is no connection of any kind between melaphyr and dolomite.

Petzholdt * found carbonate of magnesia in almost every limestone in the Tyrol, sometimes to the extent of 8·5 per cent. Hence, he considers that the question as to the source of the magnesia in dolomite, is identical with that as to its source in stratified limestone. Since, moreover, the gradual passage of limestone into dolomite is everywhere recognizable, both geognostically and chemically, he infers that the deposition of dolomite immediately succeeded that of limestone. With regard to this view, he refers to the known fact, that when a portion of the carbonic acid has been disengaged from a solution of the bicarbonates of lime and magnesia, the carbonate of lime is precipitated before the carbonate of magnesia. In this way he accounts for the preponderance of lime in the underlying beds of stratified limestone, and for the preponderance of magnesia in the upper beds of dolomite. Thus, for instance, the amount of magnesia increases towards the upper part in the Saltaria gorge and at the Celva mountain; the proportions of lime to magnesia being, in the former case, as 1000:108:825:886, and, in the latter, as 1000:10:11:12. The reason why the stratified limestone is not crystalline, while the dolomite is, he considers is to be sought in the fact, that the lower beds contain 12·7 per cent. silica, alumina, and peroxide

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* Beiträge zur Geognosie sou Tyrol. Leipzig, 1843, p. 231.

of iron; while the dolomite contains only 0·5 per cent. of these substances.

Cotta* believes that the crystalline condition of many kinds of dolomite is the result of a molecular change in a muddy sediment, and that this crystallization was brought about by the volcanic action which protruded the melaphyr in the Fassa district.

It would not be likely that in such a muddy sediment, the lime and magnesia would be just in the right proportion to form dolomite, or that it would be free from accidental admixtures. For the separation of these, and of the excess of lime or magnesia, a long-continued process of extraction would have been requisite.

The intimate connection between limestone and dolomite, that has been illustrated by so many examples, does not admit of being reconciled with the opinion that both have been deposited in like manner from the ocean. It is true the ocean has furnished the material for the production of dolomite, either as the dolomitic portion of limestone, or, when the alteration took place in the ocean, by the substitution of magnesia for lime; but so long as it cannot be shown that there is any product of marine animals in which the carbonates are in equivalent proportions without any admixture of carbonate of lime, there is no ground for supposing that dolomite is produced by direct deposition. It has already been shown, moreover, that by the evaporation of water containing both carbonate of lime and carbonate of magnesia, these substances are, for the most part, deposited separately.

Breithaupt† mentions that in the bed of the Neckar, as at Cannstadt, there is a constant production of dolomite, which cements together the gravel. Walchner,‡ in speaking of these conglomerates, calls the cementing substance calcareous tuff. A similar conglomerate, formed in the Rhine at Bonn, contains a cementing material consisting of—

Carbonate of lime	97·92
„ magnesia	1·57
Peroxide of iron	0·51
	100·00

The fact, that in the dolomite of the Tyrol the amount of magnesia is greater in the upper parts of the mass than at the lower points, merely proves that the production of dolomite has advanced downwards, and would necessarily be the case if it were effected by surface water. The case certainly appears more complicated where, as at Eichstädt, large masses of dolomite rest upon limestone, and are covered by calcareous slate that is remarkable for its impressions of fish remains.*

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* Geolog. Briefe aus den Alpen., p. 208.

† Die Paragenesis, p. 46.

‡ Darstellung der geogn. Verhält der Mineralquellen, etc.

Taking into consideration all the facts known with regard to dolomite, so far as it occurs as a rock mass, it can only be regarded as a product of the alteration of limestone in the wet way; and there is no mode of alteration that is more probable than the substitution of carbonate of magnesia present in water for a portion of the carbonate of lime in limestone, or the extraction of the greater part of carbonate of lime by the water permeating the limestone. With regard to the production of dolomite or bitter-spar in cavities and fissures, nothing can be determined unless they are regarded as products of the alteration of carbonate of lime.

CHAPTER LIV.

Augitic Rocks.

The principal rocks containing augite as an essential constituent are melaphyr, dolerite, some kinds of lava, basalt, and augitic porphyry. In all the rocks it is associated with a felspar that is either labradorite, or has a composition closely analogous to it. The augite in melaphyr has a composition which appears to be very nearly the same as that of hornblende, and in many instances it has probably undergone alteration. The various alterations of augite, already pointed out, will serve to elucidate the alteration of rocks containing augite and labradorite, but it is probable that the decomposition and alteration of an intimate mixture of these minerals may present some features different from those observed in the case of the same minerals separately. Among the constituents of true basalt and augitic lava, olivine is the most characteristic; melaphyr does not contain any, or but very little, of this mineral. Even basalt, that contains little or no olivine, is very different from melaphyr, the most marked difference being in the density, that of melaphyr being from 2·63 to 2·75, and that of basalt from 2·85 to 3·67. These rocks may be divided into two classes—basalt, dolerite, and augitic lava, in which augite preponderates; labradorite and melaphyr, in which the reverse proportion obtains.

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* L. v. Buch.—Geognost. Briefe. p. 8. See also Cotta, Geol. Briefe. p. 180.

The surface of augitic porphyry is generally much acted upon by exposure to the atmosphere; the matrix is decomposed, loses its colour and coherence, and is washed away by surface water, leaving the augite or uralite crystals projecting from the surface, and giving it a rough appearance.

In the augitic porphyry at Kuschwinsk the augite crystals are covered with a crust of uralite, and are sometimes entirely converted into the latter. The felspathic constituent—probably labradorite—is converted into kaolin at the surface of the rock, and the greater portion of it has assumed an earthy character. Both it and the kaolin are readily washed away by surface water, leaving the uralite and augite crystals projecting. The conversion of the augite into uralite, and of the labradorite into felspar, probably took place at the same time. Sometimes, augitic porphyry is vesicular, the drusy cavities containing calc-spar or calcedony. Sometimes, also, it resembles a conglomerate, as to the east of the Auschkul lake, where rounded fragments of augitic porphyry, or detached augite crystals are cemented together with white calc-spar and a reddish somewhat decomposed zeolitic substance.

Augitic porphyry contains as accessory constituents iron pyrites and magnetic oxide of iron. The latter is, undoubtedly, a product of decomposition, and the former has been produced by the joint influence of sulphates and organic substance. In six varieties of augitic porphyry analysed by Girard, the amount of water varied from 0·3 to 2·25 per cent.

Melaphyr occurs very frequently in Rhenish Bavaria. At the eastern side of the Nahe, near Münster-am-Stein, it first appears. I have had an opportunity of studying the phenomena presented by the decomposition of this rock. From Münster upwards along the left bank of the Nahe, immediately above the red rock, consisting of felspar porphyry, masses of melaphyr are met with. Some of the blocks are entirely covered with carbonate of lime, and far into the interior, the mass effervesces with acids, although only at detached spots. At the surfaces of junction, however, there is always effervescence. At many places the contact of melaphyr with shale may be observed, but there is nowhere any indication of a fritted condition of the latter rock at these places. The shale effervesces with acids, not only at the surface of contact with the melaphyr and at the cleavage surfaces, but also throughout the entire mass. At some places, also, quartz veins traverse the melaphyr. At other parts the melaphyr in contact with shale is so far decomposed and ochrey that it no longer effervesces with acids. Here, also, the shale does not effervesce with acids. Here and there between the detached masses are considerable deposits of calc-spar, and veins of calc-spar may be traced for a distance of several feet in a more or less vertical direction. Where there are narrow cracks, streaks are recognizable as in basaltic columns, where the blueish colour passes into an ochre-yellow; this is the case especially at places where no actual interstice is recognizable, showing that water has penetrated even these narrow spaces.

In the Alsenz valley, above Alt Bamberg, there is a quarry close to the road where the melaphyr is very much decomposed. It presents a spherical structure, and may be separated into concentric masses. This result of decomposition is also presented very distinctly by the rock upon the heights of Niederkirchen. The less-decomposed rock in which the mineral constituents can still be recognised, effervesces very copiously with acids. That which is still more decomposed, and has become almost earthy, either does not effervesce at all, or only where the decomposition is less advanced. In this case, undoubtedly, the carbonate of lime resulting from the decomposition, has been entirely washed away. Near Niedermoschel and above Mannweiler, the melaphyr is very compact and hard, apparently quite unaltered. Still, acids produce considerable effervescence, though the outer crust does not effervesce at all.

Below Rockershausen, in the Alsenz valley, close to the road, there is a melaphyr dyke five feet thick, traversing shale. The mass of this dyke effervesces copiously with acids, and is traversed by veins of calc-spar. At some parts, however, it is not decomposed, and there it does not effervesce. The adjoining rock is generally very much decomposed at both sides of the dyke.

At the gold mines near Seelen, in the neighbourhood of Niederkirchen, there is a thick vein of carbonate of lime traversing the melaphyr, and extending from one ridge to another opposite. Small veins of calc-spar extend from this mass into the adjoining rock. These probably represent the channels through which the water passed, and extracted from the highly decomposed melaphyr the carbonate of lime that was afterwards deposited in the dyke. There is a distinct saalband, consisting of an argillaceous mass, and fragments of calc-spar.

Shale also occurs here so highly impregnated with carbonate of lime that it effervesces with acid throughout its entire mass. Some of it, however, effervesces only where there are narrow cracks, and some of the shale which has no cracks does not effervesce at all. Consequently, the carbonate of lime has been infiltrated, and it has, undoubtedly, been derived from the neighbouring melaphyr.

At the Sattelberge, in some abandoned limestone quarries, the melaphyr is converted into an earthy mass, traversed by innumerable veins more or less vertical, and varying from the thickness of paper to several inches wide. The mass in these veins is red, and effervesces copiously with acids, being in fact highly ferruginous carbonate of lime. The adjoining rock also presents effervescence.

In this locality it is very evident that the carbonate of lime in melaphyr is a product of the decomposition of silicates of lime. Thus, for instance, the perfectly sound and perfectly decomposed portions of the melaphyr do not effervesce at all. In the latter case, the whole of the carbonate of lime has been removed, and in the former the decomposition has not yet commenced.

Below Dannenfels, on the side of the Donnersberg, there is an abandoned quarry, where the decomposition can be traced through all its phases. The normal colour of the melaphyr is rather lighter than that of basalt. It effervesces with acids throughout its entire mass, but the evolution of gas takes place only from detached spots. This melaphyr is traversed by abundant veins of quartz, frequently as fine as pencil marks. Between these veins and the melaphyr there is almost always a perceptible effervescence. Some of these veins consist of colourless quartz, others of jasper.

The original blue colour of the melaphyr passes into green, and this green substance does not effervesce with acids, even when it is traversed by veins of jasper. It is clear that the first stage of the decomposition gives rise to the green colour, because fragments which are green at the surface are blue at the interior, while the green colour extends along the cracks into the interior of the mass. It can scarcely be doubted that this green colouration is a consequence of the elimination of lime, and, probably, also of protoxide of iron. It closely resembles the colour of green earth, and calls to mind the association of that substance with carbonate of lime.*

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* English edition, ii, 329.

When the decomposition extends still further, ochre-yellow patches appear, which are sometimes so intimately blended with the green portions that the rock has a yellowish-green colour. Ultimately the green colour entirely disappears, and the whole mass becomes ochre-brown, especially at the surfaces of detached portions. None of these products of alteration effervesce with acid. The ochre-coloured mass is very friable, and very readily crumbles under the hammer.

The above-mentioned jasper always occurs in small fissures in the melaphyr, more rarely in drusy cavities. Consequently, its subsequent production in the wet way cannot be doubted in the least. It appears to occur chiefly in the lower parts of the melaphyr, and, therefore, appears to be rather deposited from water penetrating from above than separated from the rock in which it occurs. Between the jasper and the melaphyr, both in veins and drusy cavities, acids always produce effervescence. Sometimes the jasper itself contains microscopic spots from which acids liberate gas bubbles.

These observations show that in the first instance the water permeating the rock has deposited in the small fissures carbonate of lime, that is recognizable only by the effervescence with acids. Then followed the far more considerable deposition of silica, partly in the state of jasper, and partly as colourless quartz. In the drusy cavities quartz crystals were produced, sometimes of a reddish or yellow colour, or covered with such a coloured film. These products are never found in the reverse order, that is to say, quartz at the sides of the fissures, and calc-spar in the middle. Fissures or cavities containing only calc-spar are very rarely met with. It appears, therefore, that the augitic and labradorite substance of this rock contains a smaller amount of silicate of lime than the melaphyr of the Nahe district and the Alsenz valley. As a general rule, the effervescence of the melaphyr of the Donnersberg is much less copious than in the case of those rocks, and it ceases to appear at all after the first alteration has taken place.

The carbonate of lime is, undoubtedly, a product of the simultaneous decomposition of labradorite and augite. It was at first removed by water, and then deposited in the small fissures and cavities of the melaphyr. The silica that was afterwards removed and deposited is, probably, the product of labradorite* only, although the circumstance that jasper occurs as a product of the alteration of augite admits of the inference that this mineral has also originated from augite.[*] According as the silica was mixed with carbonate of iron or not, the siliceous substances deposited would be coloured or colourless. Upon the quartz crystals in the cavities there is iron-ochre, which effervesces with acids, and, consequently, contains carbonate of lime. If the red colouring substance of jasper is only peroxide of iron, it may be inferred that the protoxide of iron in the water was peroxidized during its deposition together with silica.

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* English edition, ii, 211.

A quarry on the load from Marienthal to Dannenfels yields a very compact melaphyr closely resembling basalt, and not effervescing with acids.

In three other quarries between Dannenfels and Jacobsweiler the melaphyr generally presents the same character as that below Dannenfels. At some places the rock is very much decomposed, and crumbles under the hammer. It does not effervesce with acid except where it is fresh, and then very slightly. Jasper occurs here very frequently.

These facts will suffice to show that the chief products of the decomposition of melaphyr are carbonate of lime, quartz, and carbonate of iron, or hydrated peroxide of iron; but that according to the composition of these rocks and other circumstances, the products of decomposition may be modified.

Jasper frequently occurs in augitic labradorite rocks. In the Ural, where it occurs very abundantly, it is always associated with green-slate, clay-slate, and augitic porphyry. In the neighbourhood of Orsk there is a considerable bed of jasper resting on augitic porphyry, and probably covered by the same rock. G. Rose[†] considers it to be a product of the action of heat on clay-slate; but it is difficult to account for such an alteration by heat, for there is no rock that has more evident signs of production in the wet way than jasper. The following analysis of the Orsk jasper by Avdeëff shows that it is by no means merely silica coloured with oxide of iron:—

Silica	79·51	98·77
Alumina	9·24	
Protoxide of iron	3·32	
Lime	4·31	
Magnesia	0·51	
Potash	0·32	
Water	1·56	

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[*] Maier.—Blum's Pseudomorphosen, p. 59.

[†] Reise nach dem Ural, ii. 185.

To judge from the analysis, this jasper is, probably, a simultaneous product of the alteration of labradorite and augite. Probably it effervesces with acids, in which case the lime would be only an admixture.

The above-mentioned circumstance, that melaphyr of a blue colour like basalt becomes green with incipient decomposition, seems very noteworthy. This change of colour is by no means seldom; indeed, it appears that all kinds of melaphyr, which present innumerable gradations of colour from blue to bright green, originally had this blue colour, and that the green tints are nothing more than the results of various degrees of decomposition of the original melaphyr.

G. Rose* speaks of a perfect transition of the augitic porphyry in the Ural into a green-slate, or into a rock with more or less schistose structure, and of various colours, from a dull greenish-grey that is sometimes light and sometimes dark; small fragments even being of dissimilar character. In the Planitz transition rocks there are similar instances of the passage of augitic porphyry into green-slate.† In the valley of Schönfels a series of different greenstone masses may be traced, comprising augitic porphyry, variolitic and amygdaloid aphanite, greenstone conglomerate, compact, hard greenstone, and greenstone slate. In the amygdaloid greenstone small granules of calc-spar occur. Between Niederplanitz and Cainsdorf there is, indeed, in several small hills, a greenish or greyish-black, compact and very hard rock, which is fissured and weathered precisely in the same manner as basalt, and presents in a quarry the columnar structure recognised by v. Gutbier, which is never observable in the greenstone of this locality. The green amygdaloid rock contains imbedded masses of calc-spar or steinmark, which are generally surrounded by a dark green or greyish-black substance, similar to chlorophæite, forming very regular layers of a fibrous texture round the imbedded masses. Some of the cavities, also, especially the smaller ones, are entirely filled or lined with this mineral.

The conversion of basalt into an earthy mass of wacke, presenting a dirty green and greenish-grey or blueish-green colour, is one among the alterations of augitic labradorite rocks. The wacke sometimes contains nuclei, consisting of sometimes spherical, sometimes flattened masses of hard greenish-black basaltic rock. It also contains augite crystals, scales of mica, and even granules of quartz. At the Pählberg* the wacke presents detached slabs, and passes directly into basalt.

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* Op. cit., ii, 544 and 573.

† Naumann. Erläut. ii. 322, et seq.

Lastly, including gabbro and hyperite among the number of altered augitic labradorite rocks, we have a large series of rocks, the initial members of which are sound augitic porphyry, melaphyr, or basalt, which, by gradual alteration like that already described, furnish innumerable varieties of greenstone, amygdaloid rock, gabbro, hyperite, etc., the final members of the series being entirely decomposed ferruginous clays.

When melaphyr is so completely decomposed that merely ferruginous clay remains, silica, lime, magnesia, and some oxide of iron, must have been separated. These products of decomposition may be removed so far away by water that they are not at all deposited in neighbouring rocks; or they may be deposited, and thus produce the alterations that are so often described as the result of contact with melted masses. Credner is of opinion that there are many instances of this kind in the coal measures of the Thuringian forest, where the strata are in contact with melaphyr.† Thus the sandstone is white, and has a prismatic structure; the schistose sandstone presents a parallel striped appearance; the shale is converted into a compact mass analogous to jasper, appearing as streaks of various thickness between the layers of white quartzose sandstone. Besides this, siliceous slate and quartz occur between the clay-slate and melaphyr, and hornstone between the greenstone and the melaphyr containing epidote.

However different these alterations may be, they all tend to show that there has been infiltration of silica into adjoining rocks. Consequently, the substances that are wanting in the decomposed melaphyr are met with in the rocks associated with it. Although in several instances the melaphyr does not present any apparent alteration at its surface of contact with other rocks, still the effervescence with acids shows that alteration has really taken place; and when lime has been separated as carbonate, the silica with which it was combined may also have been removed, unless the place of the lime had been taken by another base—for instance, magnesia or potash—and some other mineral produced. As a general rule, calc-spar and brown-spar occur in the melaphyr described by Credner, sometimes as veins, and more frequently as nodules and hollow masses. But when the melaphyr is amygdaloid, the crystalline character is less marked, and the

* Op. cit., p. 479.

† N. Jahrb. für Mineral. etc. 1843, p. 291.

matrix becomes a ferruginous clay. This description shows distinctly the connection between the presence of calc-spar, and brown-spar, and the decomposition of the rock. It seems in such instances impossible to assume that these spathic minerals have penetrated into the rock from below, when the substance of which they consist is precisely that of which the ferruginous clay is deficient, except that it exists in the state of carbonates instead of as silicates.

There are few rocks that have been more frequently analysed than the augitic rocks, so that there would seem to be but little probability of doubt as to their composition. According to previous geognostic observations, these rocks appear to present the greatest diversity in their composition, so that very often within an area of a square mile there may be an innumerable variety of augitic rocks, which are considered to be the products of eruption. The question how so many different masses could have been protruded from the melted mass in the interior of the earth through the fissures in sedimentary strata, is one that should have suggested itself to those geologists who hold this view of their origin; for sometimes the rocks in each fissure are different, and sometimes the same mass constituting a mountain of considerable size, presents at different parts a great diversity of mineral character. However, the explanation of this point has not been attempted. Nor has any attention been paid to the possibility that the erupted masses, which have been for ages exposed to the influence of the atmosphere, might have had some of their constituents extracted by water and others introduced in their places, or otherwise, although the presence of various substances in the water of springs, and the occurrence of pseudomorphs in rocks, furnished ample evidence of this abstraction and introduction of material. Where rocks were not weathered, no suspicion was entertained of alteration by the action of water, in the belief that such alteration must always be attended with weathering. It has been supposed that whole mountain ranges have been, as it were, roasted, and that in this way sedimentary strata have been converted into crystalline rocks. The question, whether these altered rocks contained all their original constituents, and those only, either remained unnoticed, or when this point was considered, the removal or introduction of constituents was sought to be accounted for by the unnatural assumption of sublimation.

The results of the analyses of augitic rocks do not always present sufficient opportunity for comparative examination. Most chemists who have occupied themselves with this subject have adopted that method which, at first sight, appears most appropriate for the analysis of mixed rocks, namely, the separation of the mass by means of acids into a portion that is decomposed, and another that is not decomposed. But this method does not by any means lead to such results as it seems to promise. If in the case of the augitic rocks, acids dissolved only the zeolitic portion, leaving the labradorite and augite entirely unaltered, the results obtained in this way would be of some value. But Karsten* found that labradorite is to some extent decomposed by acids. Even the augite does not altogether resist the action of acids. Considering, also, the observations made by Girard† with regard to the behaviour of the mineral species generally occurring in augitic rocks, and the remarks previously made with regard to olivine,‡ it becomes evident that hydrochloric acid does not merely decompose the zeolitic portion of augitic rocks, but that according to its strength, the temperature, and the time of its action, it also decomposes, more or less of the labradorite and augite portions.§ Any doubt with regard to this fact would be removed by the behaviour of lava with acids. This, like other augitic rocks, is resolved into a soluble and an insoluble portion; but the former cannot consist of zeolite substance, because lava does not contain water. L. v. Buch, Elie de Beaumont, and G. Rose,‖ agree in the opinion that lava consists of a mixture of augite and labradorite. The lava of Ætna, analysed by Löwe,¶ consisted of a grey mass, with distinct imbedded crystals of labradorite and augite, and granules of olivine. The former was most abundant, and the olivine least so. Hydrochloric acid decomposed one-fourth of the mass, and it must be inferred that the labradorite was completely decomposed by the acid, for the whole of the alkalies were in the dissolved portion. The acid had, however, dissolved 27 per cent. of protoxide of iron, which could not have been derived from either the labradorite or olivine, but from the augite. The matrix of this lava could not have been an heterogeneous mixture of silicates, because its composition coincides with that of augitic porphyry. Therefore, whatever may be the advantage of this method of analysis in some instances,

* Poggend. Annal. lxiii, 123.—Compare also Bergemann—Op. cit. p. 7.
† Rammelsberg.—Handwörterbuch, i, 78.
‡ English edition, ii, 515.
§ Bergemann, op. cit. p. 5.
‖ Poggend. Annal. xxxvii. 188, and xxxiv. 29.
¶ Ibid., xxxviii, 159.

it cannot render any service when the several constituents of a rock are liable to a more or less complete decomposition by the action of acids.

The zeolitic portion of those rocks in which, from the presence of water, its existence may be inferred, is undoubtedly a product of the partial decomposition of labradorite, and its amount will be proportionate to the advanced state of the alteration of this mineral. Consequently, different specimens of melaphyr that were originally identical, may yield different amounts of zeolitic substance, according to the degree of alteration, so that the results obtained by treatment with acids really indicate only the extent to which the rock is altered.

The following considerations will show what conclusions may be drawn from the results obtained in the analysis of augitic labradorite rocks, although from the nature of the case much may remain undetermined; but this objection would not be in any way removed by the separate analysis of the portions soluble and insoluble in acids, and the adoption of this method would only lead to confusion.

In labradorite, as in aluminous augite,* the relation of the oxygen in the silica to that in the bases is as 3 : 2. According to the analyses of labradorite, the amount of silica lies between 52·3 and 55·75 per cent., in aluminous augite it is between 47·05 and 51·8 per cent., and in the augite without alumina it is between 43·0 and 57·5 per cent., when the iron-manganese augite analysed by Thomson, which was evidently much decomposed, is excluded.

Consequently melaphyr, or basalt, or lava, consisting only of labradorite and aluminous augite that have not undergone decomposition, cannot contain more than 55·75 per cent. silica, or less than 47·05 per cent. The maximum amount would be found only when labradorite was greatly preponderant, and the minimum only when this was the case with regard to augite. When, however, the amount of silica in a rock consisting only of labradorite and augite exceeds the above maximum, and when, consequently, the proportion of the oxygen in the bases is less than two-thirds of that in the silica, this is a sure sign that decomposition has commenced, and that bases have been abstracted from these minerals, so that the amount of silica was relatively increased. When, on the contrary, the amount of silica in such a rock is less than 47·05 per cent., and the proportion of oxygen in the bases is more than two-thirds of that in the silica, it is equally certain that the rock is somewhat decomposed, and that silica has been abstracted, so that the amount of bases has relatively increased.

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* English edition, ii, 206 and 313.

In augite without alumina the oxygen of the silica amounts to double that of the bases. Consequently, in a rock consisting of such augite and labradorite, the oxygen of the bases, or the oxygen quotient, will amount to 0·667, or 0·5 that of the silica. When the rock contains equal amounts of labradorite and augite without alumina, the oxygen quotient would be 0·5835. In such rocks the amount of silica may approach the two extremes of 57·5 and 47·05 per cent., when the augite preponderates and is not decomposed. But when the silica amounts to more than 57·5 per cent., there must have been a separation of bases, and when it is less than 47·05, it must have been partially abstracted. As the amount of silica increases, the oxygen quotient of course decreases, and approximates to the value of 0·5, and as the amount of silica decreases it tends towards 0·667.

These considerations show that the presence of aluminous augite, or of augite without alumina, can be determined with certainty only when the rock is quite unaltered, or when the augite crystals are so well developed that they can be analysed separately, for in that case it may be assumed that the augitic matrix has the same composition as the augite crystals imbedded in it. However, since this case rarely occurs, the former indication is the only one that is generally to be had. With regard to this point, the greenish or even ochre-brown colour of the rock, its effervescence with acids, its hydration, and the presence of organic substances, are the characters to be observed.

From the amounts of potash and soda it might be inferred whether or not the alumina equals or exceeds in amount the quantity corresponding to the composition of labradorite, if those amounts were not so variable, from 4·27 to 10·57 per cent. in different specimens of labradorite. If, therefore, labradorite crystals do not occur in the rocks, so that a separate analysis can be made, and the relative proportion of alumina and alkalies in the matrix determined from that found in the crystals, it cannot be ascertained, by means of an estimation of the alkalies in the rocks, whether the alumina belongs merely to the labradorite, or to the augite also. The total amount of alkalies and lime in labradorite varies between much narrower limits—13·8 and 17·47—because these bases replace each other. If lime were not a common constituent of labradorite and of augite, the amount of alumina might be determined with certainty from the oxygen of these three bases.

These remarks will show how difficult it is to determine the very essential question whether the augite in any particular rock contains alumina or not. This difficulty is by no means lessened by the separate analysis of the soluble and insoluble portions.

When an augitic rock appears but little altered, while at the same time the amount of silica exceeds the above-mentioned maximum quantity for augite (55·75 to 57·5 per cent.), there is good reason for inferring the presence of some other kind of felspar, such as oligoclase, or albite. These varieties of felspar can seldom be distinguished from labradorite by a mineralogical examination. The treatment of the coarsely powdered rock with acid may sometimes furnish an indication, since oligoclase and albite are so much less readily decomposed by acids than labradorite. Oligoclase contains less lime than labradorite, and albite scarcely any, so that acids would extract most lime from labradorite and least from albite. The oxygen quotient of oligoclase is 0·444, and that of augitic rock containing this kind of felspar would therefore approximate to this value in proportion to the amount of it in the rock.

The occurrence of oligoclase in augitic rocks has been satisfactorily proved. Thus the augitic porphyry from near Ajatskaja* contains it. In this porphyry the augite crystals are accompanied by uralite, although seldom. The presence of oligoclase, or labradorite, or of both, in the greyish white matrix might be ascertained as above described, by estimating the amount of silica. G. Rose conjectures that the crystals imbedded in antique porphyry and in the green porphyry of the Harz, which closely resemble those in the augitic porphyry of Ajatskaja, are oligoclase. However, the analyses made by Delesse do not seem to confirm this conjecture so far as regards antique porphyry. On the other hand, it has been proved by an analysis by Rammelsberg, that the large pale green crystals, sometimes an inch long, imbedded in the dark green fine-grained matrix of a porphyry near Gevelinghausen, are oligoclase. v. Dechen† considers it probable that the larger crystals in many of the porphyritic rocks described by him, and occurring in the vicinity of Brilon, are oligoclase, and that only the small acicular crystals upon the fractured surface are labradorite.

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* Poggend. Annal. lii, 470.—Compare also G. Rose.—Reise nach dem Ural i, 143, and Poggend. Annal. xxxiv, 20, and English edition, ii.

† Ibid.

Even in a lava dyke at Havnefjord, in Iceland, a felspar occurs partly in druses, partly constituting the matrix, and associated with augite crystals and titanate of iron, which according to Forchhammer's* analysis contains 61·35 per cent. of silica, and is nothing more than oligoclase in which lime constitutes the chief portion of the stronger bases. The augitic constituent of this lava was carefully removed by means of a magnet and was found to contain only 50·81 per cent. silica. According to Deville's† analysis, oligoclase also occurs in a recent lava at the side of the Peak of Teneriffe. According to Plattner's analysis of a felsite from Hammond, in New York, it contains oligoclase—Breithaupt's loxoclase—together with augite, graphite, and calc-spar.

These examples show that the presence of oligoclase may be inferred with great probability when the analysis of an augitic rock indicates a greater amount of silica than from 55·75 to 57·5 per cent. when the rock does not appear to be much altered. On the contrary all previous examinations appear to show that albite does not occur in these rocks.

When the amount of silica in an augitic rock is less than 47·05 per cent., and at the same time it appears to be little altered, it may be inferred, that besides labradorite and augite, there are other minerals present which contain less silica than either of these. Among the varieties of felspar, anorthite is the only one in which the silica, 44 per cent., is less than in labradorite, and the presence of this mineral might be inferred if it did not occur so very seldom in augitic rocks.

The not unfrequent occurrence of nepheline in these rocks, and the considerable amount in which it is sometimes present, as for instance in the dolerite near Löbau, in Lusitania, where it almost equals the amount of augite, would reduce the amount of silica in the rock, since that mineral contains only from 43 to 45 per cent. of silica. But a more careful examination of a rock before analysis would readily indicate the presence of nepheline.

Among the ferruginous minerals, garnet, vesuvian, tourmaline, and olivine, contain less silica than augite. Garnet sometimes occurs together with augite.‡ At the Kapellenberg, near Rothweil, and also near Endingen, black garnet occurs in a fine-grained dolerite, containing little augite; but this is too isolated an instance to admit of inferring its presence in the matrix of augitic rocks containing little silica. This remark also applies to vesuvian, and tourmaline never occurs in augitic rocks.

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* Journ. für prakt. Chemie xxx, 389.

† Comptes Rendus, xix, 46.

‡ A scoriaceous augitic rock, containing much mica, occurring in, and on the banks of the lake of Laach, contains cavities with white incrustations, which, according to Blum, consist of decomposed nepheline crystals, the form of which may be recognized by the aid of a good magnifying glass.

The presence of olivine may be inferred with the greatest probability when the amount of silica is less than the normal quantity, since this mineral so constantly occurs in augitic rocks, and especially in basalt. But its presence can be recognized so easily by mineralogical characters, that chemical analysis is unnecessary.

The presence of varieties of mica with a small amount of silica would also reduce the amount of silica in augitic rocks. However, this mineral may be so easily recognized, even in the smallest laminæ, that for determining its presence or absence, analysis is as unnecessary as in the case of olivine.

The more magnetic iron ore an augitic rock contains, the more its amount of silica is under the normal quantity, provided this mineral is not a product of decomposition; but even then the amount of silica may be less, owing to the removal of silica during the decomposition of the protosilicate of iron. When, however, the eliminated silica remains in the rock, either as quartz or otherwise, the presence of magnetic oxide of iron cannot affect the amount of silica. The latter case only can be ascertained with certainty when the magnetic oxide of iron is associated with quartz. Even when magnetic oxide of iron is not recognizable mineralogically, its presence may be detected by means of the magnet. In this way the rocks may be recognized in which the amount of silica is probably reduced by the presence of magnetic oxide of iron.

Delesse* found the matrix of all the melaphyr that he examined magnetic, and he regards this as a general character of this rock. Some kinds of augite are also magnetic, as, for instance, those of the Fassathal, and from some still active volcanoes, the salitite and cocolite of Norway, and the augite of Belfahy. Hypersthene and bronzite also act upon the magnet.

Although it is probable that the magnetic oxide of iron in these minerals is a product of decomposition, it would be interesting to analyse magnetic augites, in order to ascertain whether they contain the normal amount of silica, or not. By this means it is probable that the question whether the eliminated silica is still present might be to some extent determined.

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* Op. cit. p. 46.

In the analysis of augitic rocks containing magnetic oxide of iron, it has been attempted to estimate the amount of the latter by extraction with hydrochloric acid. I have found that the results thus obtained are always too high, because the acid extracts some protoxide of iron from the augite.

The above considerations show how much the analysis of augitic labradorite rocks may be simplified when the rock is analysed as a whole, instead of making separate analyses of the soluble and insoluble portions. By this means the operation is reduced to less than one-half, and even the mere estimation of the silica is generally sufficient to show whether, besides augite and labradorite there are other minerals present not recognizable by the eye. The determination of the relative amounts of labradorite and of augite is equally untrustworthy, whether the rock is separated into a soluble and insoluble portion, or analysed as a whole.

The separation of zeolitic substances from labradorite would not, even if possible, have any value, because those substances are not original constituents of the rocks, any more than the zeolites in cavities. The attempt to effect this separation in the case of the labradoritic rocks is quite as inappropriate as in the case of labradorite crystals containing a considerable amount of water. The specimens of labradorite analysed by Delesse, containing as much as 2·5 per cent. of water, probably contained as much zeolitic substance as melaphyr containing the same amount of water. The amount of zeolitic substance in an augitic rock would be directly proportionate to the amount of water it contained, and this is probably the best indication of the amount of the former.

The variations in the proportions of the constituents of an augitic rock, given by the separate analysis of the soluble and insoluble portions, and the indefinite composition of the minerals corresponding to each portion, show how little dependence is to be placed on this method of analysis. Thus Bergemann, in attempting to determine the nature of the mineral constituents of various augitic labradorite rocks, found that there was always a surplus of silicates, sometimes ferruginous and sometimes not, which varied in amount from 11 to 35 per cent. in different rocks, and did not correspond in composition with any known minerals.*

Such indefinite residues would always be obtained, for it must be remembered that it is precisely the augitic labradorite rocks which are the least durable, and which in course of time undergo the greatest degree of alteration, without, however, being so much

* Op. cit. p. 6.

changed in appearance, except when completely decomposed, that their original condition is no longer recognizable.

It has already been shown that considerable errors may be incurred by attempting to calculate the amount of labradorite from the amount of alkalies. By regarding the remainder as augite there is great room for different results, on account of the great variation in the composition of this mineral. The portion dissolved by acid consists of magnetic iron ore, olivine, etc., and contains also decomposed portions of labradorite and augite, and in deducting the constituents of the two former minerals, when their presence has been recognized mineralogically, still further errors are incurred. It is obvious then, that this mixture of dissolved substances, influenced by all the errors of analysis and calculation, as well as by the alteration and decomposition that the rock may have undergone in the course of time, would not present any similarity with the composition of any known mineral.

But since augitic labradorite rocks are crystalline, or in other words consist of definite minerals, it is precisely the indefinite character of this portion dissolved by acids that leads to the conclusion either that the method of analysis is defective, or that these rocks have in the course of time undergone alteration by the abstraction of constituents, and by infiltration. If this alteration is not admitted, and if at the same time it is held that the analytical method is exact, it must, on the contrary, be inferred that crystalline rocks may contain amorphous minerals of indefinite composition. However, when rocks are found in which the mineral constituents are throughout distinctly crystallized, and which do not contain any matrix, and others again in which the larger crystals are imbedded in a matrix, consisting of a mixture of the same crystalline minerals less well developed, but recognizable by means of the microscope, it is evident that these rocks cannot contain minerals of indefinite composition. Lastly, when rocks are found in which crystals cannot be recognized, either by the naked eye or by aid of the microscope, but which in their external characters and by analysis are found to present the greatest resemblance to those rocks in which definite minerals can be recognized, it would be inconsistent to assume that they consist of a heterogeneous mixture of indefinite minerals, and, therefore, to exclude them from among crystalline rocks. If, however, each and every crystalline rock consists of definite crystalline minerals, and if at the same time the separate analysis of the soluble and insoluble portions of these rocks furnish results that do not correspond with the composition of any known mineral, this can only be because this method of analysis does not admit of any accurate separation of the minerals by treatment with acid, or because the minerals are already more or less altered. There can be no doubt that both these causes are combined, for even when the crystalline rock is analysed as a whole there is an excess of certain constituents, which can only be due to the altered condition of the minerals.

After these remarks we will proceed to the consideration of the analyses of augitic labradorite rocks.

A. MELAPHYR.

Melaphyr has been examined by v. Bibra,* Bergemann,† and Delesse.‡ Bergemann analysed separately the portions soluble and insoluble in acids, so that it will be necessary to add the results together, in order to compare them with those obtained by Delesse, who analysed the rock as a whole. Several of the rocks examined by him contained carbonates of lime and protoxide of iron, the amounts of which were estimated; and since the carbonic acid was not an original constituent of the rocks, but had been introduced during their alteration, this acid is deducted. The amounts of protoxide of iron in the carbonate and magnetic oxide of iron, as well as that corresponding to the hydrated peroxide, are added, and the water of the latter substracted. The results thus obtained are distinguished as reduced results.

	I.	II.	III.	IV.	V.	VI.
Silica	53·17	50·79	49·82	54·42	53·55	55·29
Alumina	19·77	27·25		20·60	19·43	18·78
Protoxide of iron ..	8.56		29·74	9·44	7·55	9·46
„ manganese	0·51			0·93	0·85	..
Lime	3·87	8·02	7·31	3·64	8·02	3·14
Magnesia	4·96	10·74	10·93	3·87		3·48
Soda	7·02			4·48	7·93	8·68
Potash	..	..	..	0·94		
Water	2·14	3·50	2·20	1·97	2·67	1·17
	100·00	100·30	100·00	100·29	100·00	100·00
O. Q.	0·571			0·559	0·522	0·522

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* Journ. für prakt. Chemie, xxvi, 29.

† Ueber die chem. Zusammensetzung einiger vulk Gebirgsarten.—Karsten's und v. Dechen's Archiv. xxi, 1, et seq.

‡ Mémoire sur la Constitution Minéralogique et Chimique des Roches des Vosges.—Mém. de la Soc., d'Emulation du Doubs, 1847.

	I A.	V A.	V B.	VI A.
Silica	52·89	53·20	53·28	55·70
Alumina	27·39	27·31	27·73	25·28
Peroxide of iron	1·24	1·03	1·50	1·71
Sesquioxide of manganese	0·30	trace	trace	trace
Lime	5·89	8·02	8·28	4·94
Magnesia	trace	1·01	0·93	0·72
Soda	5·29	3·52	7·38	7·04
Potash	4·58	3·40		3·53
Water	2·28	2·51	0·95	0·77
	99·86	100·00	100·00	99·64
O. Q.	0·622	0·624	0·640	0·567

I. Blackish-green matrix of a remarkably characteristic melaphyr from Belfahy, in the Vosges, containing large crystals of labradorite.

II. Dark green matrix of a breccia-like melaphyr near Puix, in the Vosges, not far from the contact with transition slate. It contains small imperfect crystals of labradorite, and more rarely granules of augite.

III. Violet-red matrix of the melaphyr at Giromagny, in the Vosges, containing many small distinct crystals of green felspar (labradorite?), and sometimes dark green augite crystals.

IV. Amygdaloid porphyry—spilite—from Emoulière, without any recognizable crystals. It contains cavities that are generally almost filled with carbonate of lime, surrounded by ferruginous chlorite.

V. Matrix of the antique porphyry from the plains of Helos.

VI. Matrix of the melaphyr at Tyfholm's Udden, near Christiania.

I A. Labradorite crystal from the melaphyr I.

The powder of this labradorite was acted upon even by cold hydrochloric acid.

V A. Labradorite crystal from the antique porphyry V.

V B. Labradorite crystal from the melaphyr between Bolzano and Colmano, in the Tyrol, described by L. v. Buch.

VI A. Labradorite crystal from the porphyry VI.

All these analyses are by Delesse.

The compositions of the matrices of the melaphyr I and VI, compared with that of the labradorite from these rocks, admit of a calculation as to the relative amount of their constituents. Assuming that the alkalies in both instances belong only to labradorite, and that the labradorite constituent of the matrix has the same composition as the crystals imbedded in it, the matrices of these rocks would consist of—

	I.	VI.
Labradorite	71·02 per cent.	81·82 per cent.
Remainder	28·78 „	18·18 „

And these remainders would consist of—

	I.	VI.
Silica	53·07 per cent.	45·39 per cent.
Alumina	0·99 „	.. „
Protoxide of iron	26·21 „	38·31 „
„ manganese	1·02 „	.. „
Magnesia	16·94 „	13·73 „
Water	1·77 „	2·57 „
	100·00	100·00

In I almost the whole of the alumina appears to exist in the labradorite, and there is a deficiency of 0·32 per cent. of lime.

In VI the alumina and lime in the matrix do not suffice for the quantity of labradorite corresponding to the alkalies. The deficiency of the former is 1·94, and of the latter 0·92 per cent.

Therefore both these rocks contain augite without alumina or lime. The presence of augite without alumina is also indicated by the amounts of silica, and by the oxygen quotients, which fall within the limits that obtain for rocks containing labradorite and augite without alumina. Among the varities of augite, the iron-manganese augite is the only one that does not contain lime. In the remainder of I, however, the protoxide of manganese amounts to only 1·02 per cent., and there is none in that of VI. Moreover, these remainders do not in the least agree with the composition of any kind of augites.

Delesse endeavoured to determine the minerals in the matrix of various kinds of melaphyr by means of a powerful microscope. He distinguished two crystalline minerals, the most abundant one of which was transparent, greenish, and could not be other than labradorite; the other was dark green, and as Delesse supposed, not augite but hornblende, because by calcining the rock the augite crystals become darker coloured, while the matrix generally assumed a brown or pale reddish colour, as is the case when hornblendic diorite and diorite porphyry are ignited. According to v. Buch, Cordier, and Keilhau, the matrix of VI also contains hornblende.

But if it is the case that the matrices of these rocks do not contain augite but hornblende, it is more intelligible why the remainders, after the constituents of labradorite have been deducted, do not contain lime, for there are varieties of hornblende—antophyllite and arfvedsonite—which do not contain any lime, or in which there is but very little. The oxygen quotient of seven kinds of hornblende without alumina is between 0·425 and 0·451, and there are only three kinds in which it is from 0·468 to 0·5. Those seven kinds of hornblende are the most characteristic, consequently their oxygen quotient may be regarded as the normal one. The chemical formula assigned to hornblende corresponds to an oxygen quotient 0·444, and this number is very nearly the mean of the above seven kinds of hornblende. Since, therefore, the oxygen quotient of hornblende without alumina is less than that of augite without alumina, it follows that the presence of the former mineral in the matrix of melaphyr would reduce its oxygen quotient more than the presence of augite without alumina. While, therefore, the oxygen quotient of melaphyr, consisting of equal parts of labradorite and augite without alumina, is 0·5835; that of melaphyr, consisting of equal parts of labradorite and hornblende without alumina, would be only 0·555. As a consequence of the smaller oxygen quotient of aluminous hornblende as compared with aluminous augite, the amount of silica in the former is greater than in the latter, being between 56 and 60 per cent. Since, moreover, it appears by the above calculation that the amounts of labradorite in the two specimens of melaphyr, I and VI, are 71 and 82 per cent., while the oxygen quotients are only 0·571 and 0·522, this circumstance also seems to favour the opinion that the matrices of these rocks contain hornblende. In the other specimens of melaphyr, also, the considerable amounts of alkalies show that labradorite must preponderate, so that the presence of hornblende in them likewise may be inferred. In addition to this, it appears that in both specimens of melaphyr, as well as in IV, and probably also in II, III, and V, the quantity of magnesia exceeds that of lime, and since in hornblende without alumina the magnesia always preponderates over lime, while labradorite rarely contains any magnesia, this circumstance is a further reason for inferring the presence of hornblende in the matrices of the melaphyr analysed by Delesse.*

Assuming that the rock II contains a labradoritic matrix, having the same composition as the labradorite I A, and supposing that the amount was as great as in I, it would have required 4·18 of the 8·02 per cent. of lime. Consequently, there would have remained 3·84 for the hornblende, which in this case would have amounted to 29·3 per cent., and thus would have contained 13·07 per cent. of lime, a quantity very nearly the same as that in grammatite and actinolite. But in I and VI there is no surplus of lime for the hornblende, after deducting the quantity requisite for the labradorite.

Delesse does not in any instance speak of hornblende crystals imbedded in the melaphyr, but only of imbedded augite. If, however, the matrices of these rocks contain hornblende, they would be peculiar on account of the association of hornblende and augite in them. The analyses of I, II, and III, show that the amount of lime is very variable. In the conversion of augite into hornblende, magnesia is substituted for lime.† It would seem, therefore, that the original mass of melaphyr was originally richer in lime, and that the amount of this constituent has been diminished in the course of time by the substitution of magnesia. Hence it is possible, that in the matrix of those kinds of melaphyr which appear to contain hornblende, augite may have existed originally, as is still the case with the rocks I and II.

If lime has been eliminated from the matrix of these rocks, it cannot be supposed that this change extended only to the augite and hornblende. The alteration of these minerals probably preceded that of labradorite, but this mineral would be equally affected at a later period. Since even the large labradorite crystals, VI A, have lost some portion of their basic constituents, as is shown by the relative increase of silica and the small amount of lime, this change is more likely to have taken place in the matrix. It is not very probable, therefore, that the augite and hornblende in the matrix of I were free from lime, and that the whole amount of lime should be regarded as belonging to the labradorite, for which it did not even suffice in I and VI.

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* As the density of labradorite is less than that of augite, the density of melaphyr must decrease in proportion as the amount of labradorite is greater. L. v. Buch has already attempted to estimate, in this way, the relative amount of the constituents of augitic porphyry.

† English edition, ii, 316.

The fact, that among all the constituents of the above-mentioned melaphyr, the lime is most variable in amount, is quite consistent with the fact that in the decomposition to which this rock is subject lime is extracted. In the amygdaloid porphyry IV, the eliminated lime occurs in the cavities. The numerous veins of quartz, which appear when the rock is calcined, undoubtedly represent the remains of the decomposed silicate of lime.

Nothing can be more opposed than the above facts to the views of those geologists who maintain that rocks have not undergone alteration when they appear fresh, and that melaphyr has been protruded in the same state that it is now found in. The impossibility of assigning to the residue left, after deducting the constituents of labradorite, a constitution at all resembling that of either augite or hornblende, even when a portion of the iron is deducted as magnetic oxide of iron, is not at all to be wondered at, for it is clear that when in the course of time a rock, consisting originally of augite, or hornblende and labradorite, is altered by the abstraction or introduction of material, the residue left, after deducting the constituents of labradorite, would not correspond with the composition of either augite or hornblende.

With regard to the melaphyr II, III, IV, and V, it cannot be determined whether the augite they contain is aluminous or not, because the composition of the labradorite they contain is not known. In IV and V the amount of alumina is nearly as great as in I and VI, so that it is probable they contain augite without alumina. This is rendered probable, also, by the fact that the amount of silica and the oxygen quotient of these rocks fall between the limits observed in rocks that are known to consist of labradorite and augite without alumina.

Delesse expresses surprise at the presence of water in the labradorite I A, V A, B, and VI A, occurring in a rock which he believes must be regarded as of igneous origin. But it seems to me still more surprising that the possibility of felspar becoming hydrated in the course of time should be overlooked. This possibility is independent of the question whether melaphyr is of igneous origin or not. The water in the hydrated peroxide of iron, which results from the decomposition of melaphyr, has certainly been introduced subsequent to the production of the rock. Delesse himself observed that the amount of water in labradorite is greater in proportion as the rock in which it occurs is greener and more waxy, while there is scarcely any water in the labradorite from rocks whose colour approaches more to grey. But the white or grey colour of labradorite is an indication that it is unaltered, and the colours which it sometimes presents indicate alteration. Delesse ascribes these colours to the oxidation of iron, and found that the pink felspar was situated in the exposed parts of the melaphyr, while that at the interior was greenish-white, and even the same crystals were of different colours.

This change of colour is attended with a diminution of density, which admits of the inference that bases have been removed, and thus seems to be connected with the first stage of alteration, which necessarily involves hydration of the mineral.

The average amount of water in the matrix of several definite kinds of melaphyr is nearly the same as that in the labradorite—from 2·2 to 2·5 per cent. When it exceeds this, and reaches from 2·6 to 3·59 per cent., the rock loses its original character, and then presents carbonate of lime and chlorite among its constituents. This is a further proof that there is a direct connection between the amount of water in such rocks and the degree of alteration, and that even the smallest amount of water indicates the commencement of alteration, which is not recognizable from the outward appearance.

The resemblance in the composition of labradorite from such remote localities is not uninteresting, and the considerable amount of potash is especially deserving of notice; but in none of these minerals is the oxygen quotient so high as in normal labradorite.

The alteration of labradorite resembles that of garnet and augite, inasmuch as water extracts the bases, and especially lime, in larger amount than silica, so that the original proportions of the constituents are altered more and more as the decomposition progresses. The water of springs rising from melaphyr or amygdaloid rocks contains proportionately much more carbonate of lime than silica, and, therefore, it is not surprising that we should find a deficiency of bases in the labradorite which the melaphyr contains.

The oxygen quotients of the melaphyr I and VI show that, compared with those of the labradorite, these rocks contain a greater portion of the bases which have been extracted from the matrices than from the crystals; and this is quite consistent with the fact that the imperfectly crystallized portions of a rock are more liable to decomposition than well-developed crystals.

The matrix of V contains quartz as veins and nodules, sometimes in the state of carnelion, showing that notwithstanding the large amount of lime in this rock, alteration has commenced. In the matrix of VI, also, there are nodules of quartz, and quartz crystals in the cavities, as well as nodules of calc-spar. In the drusy cavities of amygdaloid rocks, quartz occurs, sometimes with and sometimes without epidote.

The presence of quartz in the matrices of the above specimens of melaphyr is the more interesting, since absence of quartz has hitherto been regarded as a characteristic of this rock. Naumann[*] mentions, under the name of green porphyry, a rock constituting greater part of the peaks of Rodersdorf, and containing, together with crystals resembling augite, a large quantity of quartz. Moreover, when the presence of quartz cannot be recognized by the appearance of the rock, it may be inferred when the amount of silica is very large, as in the melaphyr VI. Delesse found that a large amount of silica in the matrix of melaphyr was accompanied by nearly as large an amount of silica in the imbedded labradorite crystals. This will be apparent from a comparison of the amount of silica in the above-mentioned porphyry and that of the labradorite crystals imbedded in it, VI A. The decomposition of these crystals, and that of the labradorite in the matrix, have, therefore, gone on together, although the former was rather less rapid.

When it is considered that melaphyr acts upon the magnet, and that this is especially the case with the quartzose variety at Rodersdorf, there is in this association of quartz and magnetic oxide of iron, an additional reason for the opinion that if melaphyr is of igneous origin, these minerals have been produced subsequently. But according to the igneous theory, it is essentially necessary to suppose that there has been a subsequent separation of quartz. But even when magnetic oxide of iron is not present, if there were an excess of silica in the original melted mass, it is certainly more probable that a more siliceous felspar would have been produced than that quartz would have been separated together with labradorite.

The cavities of the melaphyr at Belfahy contain calc-spar, containing some carbonate of iron, but no carbonate of magnesia. In another melaphyr from Francogney there is a considerable amount of disseminated carbonate of lime. In these cavities the carbonate of lime is very frequently accompanied by a green fibrous mineral which covers it, and has the composition VII.

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[*] Erläuterungen, etc. p. 142.

	VII.	VIII.
Silica	31·07	27·81
Alumina	15·47	14·31
Peroxide of iron	22·21	25·63
Protoxide of manganese	traces	2 18
Lime	0·46	..
Magnesia	19·14	14·31
Water	11·55	12·55
	99·90	96·79

This mineral, which Delesse calls ferruginous chlorite, occurs with just the same characters in antique porphyry, in the augitic porphyry of the Tyrol and the Ural generally, in all kinds of melaphyr, and in the drusy cavities of all trapp rocks. Green earth appears to be only a particular variety of this mineral, to judge from the similarity of its composition, and VIII, that from the magnetic iron in Delarne. According to Delesse this ferruginous chlorite never occurs together with labradorite crystals, but only in the amygdaloid portions.

There cannot be any doubt that minerals occurring in cavities are products of infiltration, and that the materials for their production have been derived from the rock in the vicinity of the cavity. In the case of melaphyr, this would consist of labradorite, together with augite or hornblende. Augite may be converted into green earth, consequently, water may extract from hornblende also the constituents of the ferruginous chlorite. But it cannot be supposed that the action of water would be limited to the hornblende, more especially since the preponderating labradoritic constituent is the more readily decomposed of the two. No doubt the whole matrix yields the constituents of those infiltration products. Comparing the composition of I with that of the ferruginous chlorite VII, it appears that the latter contains four times as much magnesia as the former. This base was, therefore, extracted by water more copiously than others; and assuming it to be entirely removed from the matrix of a given rock, the result would be as follows:—

	Matrix.		Chlorite.		Residue.
Silica	205·18	—	31·07	=	174·11
Alumina	76·29	—	15·47	=	60 82
Peroxide of iron	36·70	—	22·21	=	14·49
Protoxide of manganese	1·97	—	..	=	1·97
Lime..	14·93	—	0·46	=	14·47
Magnesia	19·14	—	19·14	=	0·00
Soda and potash	27·09	—	..	=	27·09
	381·30	—	88·35	=	292·95

The constituents of this residue would have partly remained in the matrix, and partly have been removed by water. The lime is often found as carbonate in the drusy cavities, mixed with the ferruginous chlorite, which is also sometimes surrounded with quartz. When the decomposition of the matrix is complete, there remain quartz and ferruginous clay quite free from lime.

It is clear that more or less magnesia, lime, soda, and potash, may be found in the matrix of melaphyr, although constituents from which infiltration products have been produced, may have been extracted from it by water, for it must not be forgotten that the mass of the substances in drusy cavities is very small in proportion to that of the rock itself. Since, according to the above calculation, the rock yielding the quantity of chlorite requisite for the production of ferruginous chlorite amounts to 4·3 times as much as the chlorite, it follows that if a rock amounting to one thousand times as much as this chlorite yielded the constituents for its production, only $\frac{1}{232}$ of the magnesia would be extracted, and this loss would scarcely be recognizable by analysis.

Quartz and epidote occur together in the cavities of amygdaloid rocks, and the ferruginous chlorite occurs together with calc-spar. This association is interesting, because the chlorite contains only traces of lime, while the epidote contains much lime, and consequently its production was not accompanied by production of calc-spar. Since, on the other hand, epidote contains less silica than the matrix of melaphyr, there would be an elimination of silica attending its production that would account for its association with quartz.

Quartz and epidote are also associated in melaphyr dykes, the former being generally in the middle, and epidote is sometimes found in the mass of the rock, communicating to it an olive green colour.

The frequent occurrence of epidote in cavities and fissures is indicative of its production in the wet way, and the above-mentioned facts show that it may originate from the matrix of melaphyr.

In the porphyry of Belfahy, iron pyrites occurs in very small amount, disseminated throughout the entire mass, showing that other processes have taken place in this rock, in which soluble sulphates and organic substance have had a share.

In the antique green porphyry, in the melaphyr of the Tyrol, of the Altai, and of Egypt, the same accessory minerals—iron pyrites, quartz, epidote, ferruginous chlorite, and calc-spar—occur grouped in the same manner as in the melaphyr of Belfahy. The melaphyr of the Tyrol is remarkable for the number of zeolites, stilbite, apophyllite, prehnite, which it contains. In that near Cazona, on the western shore of the Lugan lake, v. Buch found so much epidote, the whole mass of the rock appeared speckled with green. This melaphyr is identical with that of Chapelotte, etc., in the Vosges.

The following analyses of melaphyr and of similar augitic labradorite rocks are by Bergemann:—

	IX.	X.	XI.	IX A.	X A.
Silica	49·29	48·22	42·72	51·75	50·78
Alumina	22·34	21·24	23·76	23·45	22·36
Protoxide of iron	0·33	0·87	..	9·55	14·75
Peroxide of iron	..	..	18·64	..	..
Magnetic oxide of iron, containing titanium	4·28	4·40	..	..	..
Lime	9·79	7·63	9·88	11·05	8·81
Magnesia	0·64	0·32	..	0·67	0·34
Soda	3·35	2·80	3·61	3·51	2·96
Potash	0 02	traces	traces	0·02	trace
Carbonate of iron	7·84	..	..	..	..
Hydrated peroxide of iron	..	11·51	..	..	..
Carbonate of lime	1·30	1·32	..	..	..
Water	0·75	1·68	2·02	..	..
	99·93	99·99	100·63	100·00	100·00
O. Q.	..	..	0·922	0·647	0·649

IX. A brownish or greenish-black rock, very like coarse-grained dolerite, from the summit of the Schaumberg. The magnetic oxide of iron was separated from the augite by means of a magnet. After treating a fragment with boiling hydrochloric acid, there remained a labradoritic mass of a white colour, containing small augite crystals. Small holes also appeared, resulting from the solution of carbonates. The loss by ignition amounted to 3·448 per cent., but neither empyreumatic, ammoniacal, or acid vapour was given off.

X. A brownish-yellow crystalline rock, occurring at the western side of the Schaumberg, and consisting of a mixture of yellow-brown and black particles. It contained magnetic oxide of iron. Hydrochloric acid left a residue of labradorite, containing crystals of augite. The rock contained a large amount of hydrated peroxide of iron, was not very hard, and was evidently much weathered. The loss by ignition was 6·7 per cent.

XI. Rock from the same locality, consisting of spherical masses, with a grey, or greenish-grey, very hard nucleus, and a brownish weathered crust. By the aid of the microscope, it appears as a very intimate mixture of white and black particles. It acts upon the magnet. The loss by ignition was 2·02 per cent.

IX A. The reduced analysis of IX.

X A. The reduced analysis of X.

	XII.	XIII.	XIV.	XII A.
Silica	50·76	49·05	60·60	52·55
Alumina	22·47	10·86	18·59	23·27
Protoxide of iron	0·04	4·55	1·30	8·41
Peroxide of iron	..	16·17	1·18	..
Magnetic oxide of iron, containing titanium	6·26	..	..	..
Sesquioxide of manganese	..	..	0·44	..
Lime	10·26	12·29	2·14	11·79
Magnesia	0·68	5·47	0·30	0 71
Soda	3·05	..	..	3·15
Mit wenig Kali	..	1·66	8·64	..
Potash	0·12	..	1·00	0·12
Carbonate of iron	3·75	..	..	..
„ lime	2·00	..	..	..
Water	0·75	..	..	..
Loss by ignition	..	..	6·45	..
	100·14	100·05	100·64	100·00
O. Q.	..	0·667	0·398	0·681

XII. Rock from the Martinstein, near Kirn, closely resembling IX.

The matrix consists of an intimate mixture of small crystals of augite and labradorite.

XIII. Melaphyr from the Pitschberg, between Metternich and Theley.

This rock resembles basalt more than any other rock in this locality. It is but slightly crystalline, contains a few very small particles of olivine, acts upon the magnet, contains a trace of carbonate of lime, and 1·87 per cent. water.

XIV. Rock from Weisselberg, near Oberkirchen.

The external appearance resembles the pitchstone at Meissen, but this is not consistent with the analysis. It is irregularly fissured, acts but little upon the magnet, loses 6·45 per cent. by ignition, and evolves an oily empyreumatic ammoniacal odour.

XII A. The reduced analysis of XII.

Assuming that the carbonates in IX, X, XII, and the hydrated peroxide of iron in X, are products of decomposition, the compositions of these rocks as given in IX A, X A, and XII A, correspond very closely with that of a mixture of labradorite and augite. The oxygen quotients agree so closely with the normal oxygen quotient of aluminous augite, that the presence of this mineral may be conjectured. The amount of silica also falls within the limits above mentioned. Therefore, both the mineralogical and chemical characters of the rocks IX, X, and XII, indicate that they are mixtures of labradorite and augite. The presence of carbonates in IX and XII shows that a part of the oxide of iron and lime have been separated from those minerals.

In the rock XI, the oxygen quotient is so high that it cannot be regarded as a mixture of augite and labradorite; but deducting the peroxide of iron, the oxygen quotient is reduced to 0·67. Bergemann regards this rock as a mixture of labradorite and magnetic oxide of iron.

This raises the question whether the composition of the rock was originally quite different to that of IX or X; or whether it has originated from either of these by alteration. By the alteration of augite, magnetic oxide of iron may be produced;* but the other products of this alteration do not occur in the rock, and its great hardness is opposed to the supposition that the constituents of augite were removed without anything being substituted in their place. It may be that ferruginous water has deposited magnetic oxide of iron in the rock and removed other constituents. This seems to be probable, from the progressive increase in the amount of iron in the rocks IX, X, and XII, and its apparent connection with the degree of alteration.

The oxygen quotient of the rock XIII agrees perfectly with that for labradorite and aluminous augite. The presence of olivine would have augmented it to some extent, but the portion analysed was selected free from this mineral. The small amounts of alumina and soda indicate a small proportion of labradorite, for even taking the whole of the alumina as belonging to labradorite, it would give only 37 per cent. This melaphyr is characterized therefore by the preponderance of augite, while in all the other rocks of this kind, the labradorite preponderates over augite. This peculiarity also agrees with the high density of this melaphyr, 2·9.

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* English edition, ii, 514.

The oxygen quotient of the rock XIV is so much below the normal value, that it cannot be regarded as a mixture of labradorite and augite. The considerable loss by ignition indicates a very advanced decomposition of a melaphyr having originally the same composition as the others, and during which the bases were removed as carbonates by water. The large amount of alkalies indicates also a displacement of lime and magnesia by those bases.

B. DOLERITE.

	I.	II.	III.	IV.	V A.	V B.
Silica	51·407	53·88	45·20	53·12	47·75	50·57
Alumina	12·283	12·04	14·40	6·14	18·87	19·98
Protoxide of iron ..	16·342	9·25	14·00	17·65	1·12	15·49
„ manganese.	1·594	..	..	..	..	..
Magnetic oxide of iron containing titanium	..	..	..	..	8·93	..
Lime	9·334	7·96	12·70	9·89	7·77	9·85
Magnesia	5·828	8·83	6·55	6·66	1·25	1·32
Soda	1·726	4·76	5·22	1·33	2·63	2·79
Potash	..	..	..	1·83	..	..
Water	..	..	2·40	1·93	..	..
Sulphuric acid	..	..	..	0·86	..	..
Volatile substance ..	1·056	2·78	..	..	..	..
Carbonate of iron ..	..	..	..	..	8·57	..
„ lime ..	..	..	..	..	2·72	..
	99·570	99·50	100·47	99·41	99·61	100·00
O. Q.	0·565	0·521	0 738	0·465	..	0·632

	Analysed by
I. Dolerite from Iceland	Auerbach.*
II. Dolerite from Strombolino, a rock at the north-eastern extremity of Stromboli, presenting joints similar to basalt.	Abich.†

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* Rammelsberg.—Handwörterbuch, p. 198.

† Geol. Beob. über die vulk. Ersch. und Bildungen in Italien, 1841, p. 620.

This dolerite has long been regarded as basalt. It has a dark greenish-black colour, is very compact, fine grained, and contains a great number of very small and distinct crystals of labradorite. It acts upon the magnet.

III. Dolerite from Fifeshire Drysdale.[*]
IV. Dolerite from an unknown locality Wrightson.[†]
V A. Dolerite from Meissner Bergemann.

This rock has often been mentioned as the type of dolerite. It acts upon the magnet. With acids it evolves carbonic acid, and the residue is a mixture of pure white labradorite, with a little black augite. It contains 1·89 per cent. water.

V B. The reduced analysis of the same rock.

	VI A.	VI B.	VII A.	VII B.	VII C.
Silica	35·01	40·94	51·4	42·6	44·5
Alumina	12·10	14·15	15·8	20·1	22·1
Protoxide of iron	3 96	20·43	6·0	..	..
„ manganese ..	..	..		0·5	..
Peroxide of iron	..	..	10·7	21·8	17·6
Magnetic oxide of iron.. ..	3·61	..	..	..	..
Lime	11·01	17·30	7·8	1·0	1·4
Magnesia	4·78	5·59	2·7	2·8	2·7
Soda, with some potash ..	1·36	1·59	4·3	1·9	1·7
Potash	..	..		0·9	1·2
Carbonate of iron	21·01	..	..	..	..
„ lime	6·74	..	..	..	..
Titanic acid	..	..	0·8	0·6	1·0
Water	..	..	..	8·8	8·6
	99·58	100·00	99·5	101·0	100·8
O. Q.	..	0·877	0·607	0 815	0·765

VI A. Doleritic rock from Aulgasse, near Siegburg Bergemann.[‡]

Greenish-black coarse-grained rock, consisting of black and green particles, the latter being at some parts fatty and translucent. Only a few granules were separated by the magnet from the powder. The rock appears very liable to weather, by which it assumes a yellowish or brown colour. It effervesces copiously with acids, and leaves a gray or spotty white mass.

VI B. The reduced analysis of the same rock.

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[*] Edinb. New Phil. Journ. xv, 386.
[†] Annal. d Chem. u. Pharm., liv, 536.
[‡] Op. cit. p. 36.

VII A. Dolerite from St. Austle, Cornwall. Ebelmen.*

Greyish-black; examined with a magnifying glass it appears as a mixture of white and black, or very dark green crystals. It is not magnetic, and seems very liable to weather, the outer portion becoming greenish-grey and pulverulent, with scattered black particles.

VII B. The weathered rock.

VII C. A friable grey mass from the outer part of the quarry. This rock resembles No. VII A in appearance, and is traversed by small veins of brown hematite.

The amount of silica and the oxygen quotient of No. VII A correspond with a mixture of labradorite and augite without alumina, rather than aluminous augite. Calculating the composition of the altered and unaltered dolerite from a given quantity of alumina, it appears that in the weathering more than one-third of the silica, five-sixths of the lime, and half the alkalies have been removed. In VII C the portion of the peroxide of iron removed has probably been reduced by organic substance. The loss of silica is indicated by the increase of the oxygen quotient The considerable amount of alkalies in the weathered rock admits of the inference that the augitic constituent was decomposed before the labradorite.

	VIII.	IX.	X.
Silica	48·83	50·25	51·87
Alumina	16·15	13·09	15·30
Protoxide of iron	16·32	10·55	11·40
" manganese	0·54	0·38	0·60
Lime	9·31	11·16	7·46
Magnesia	4·58	9·43	8·66
Soda, with some potash	3·45	..	3·90
Potash	0·77	4·92	0·85
	99·95	99·78	100·04
O. Q.	..	0·637	0·610

VIII. Lava from Ætna, etc. Lôwe.†

The stream which destroyed great part of Catania in 1669.

IX. Lava from the bottom of the crater in Stromboli } Abich.‡

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* Ann. des Mines, 4, xii, 627, and Rammelsberg.—Handwörterb. 4th Suppt., p. 46.

† Op. cit.

‡ Op. cit. p. 122.

X. Very light scoriæ from the island Ferdinandia, elevated in 1831 above the sea to the south-west of Sicily } Abich.*

In the dolerites I and II the amount of oxygen in the bases is less than two-thirds and more than half that in the silica. It might therefore be inferred that both contain only augite without alumina. The rock II contains labradorite and magnetic oxide of iron. If the latter is a product of alteration, and if the silica corresponding to it is still in the rock, its oxygen would belong to the bases; but if, on the contrary, the silica has been removed, the oxygen of the magnetic oxide would have to be deducted, and then the oxygen of the bases would be little different from half that of the silica. However, this relation does not agree with the presence of a number of labradorite crystals, so that it can only be supposed that this rock has in the course of time lost some of its bases. Abich's calculation that this rock contains 41 per cent. labradorite and 59 per cent. augite is certainly incorrect.

In the rocks III and IV, the relative amounts of oxygen show that the rock cannot consist of a mixture of labradorite and augite; for in III the oxygen amounts to more than two-thirds, and in IV to less than half that of the silica. Therefore, if these rocks are dolerite, they are very much decomposed, one having lost much of its silica, the other much of its bases. The analyses of normal and decomposed basalt, by Ebelmen, show that the alteration of that rock consists sometimes in the separation of silica, sometimes in the separation of bases, and there cannot be any doubt that this is also the case with regard to dolerite.

The composition corresponding to the reduced analysis of the dolerite from Meissner, V B, and the oxygen quotient corresponding to it agrees almost exactly with a mixture of labradorite and aluminous augite. Even if the magnetic oxide of iron has not originated from the decomposition of augite, and therefore the oxygen it contains is not to be deducted from that of the bases, the difference would not be considerable.

This dolerite is often compared with the Schaumberg rock, and there is indeed some analogy between them when the reduced analyses are compared.

It is of especial interest that the Ætna lava, No. VIII, corresponds exactly in composition with a rock that consists solely of labradorite and aluminous augite, since this lava contains only a few particles of olivine, besides labradorite and augite crystals, and since the portion analysed does not seem to have contained any olivine. But since this lava, like that of Val di Bove, contains some magnetic oxide of iron, the oxygen quotient is somewhat reduced.

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* Op. cit. p. 74.

Abich has pointed out the great similarity in physical characters between the lava of Ætna and the dark coloured rocks at the upper edge of the Val di Bove, which, consisting of an intimate mixture of labradorite and augite, act considerably on the magnet, and are decidedly dolerite. Another lava, which flowed slowly over the upper edge of the Val di Bove in 1838, contains labradorite and augite, though the forms are less definite. Abich infers similarity in the composition of these lavas from the similarity of density and the amount of silica.

	Density.	Amount of Silica.
Dolerite from the upper edge of the Val di Bove ...	2·8565	49·94
The lava of 1838	2·9407	48·98

The oxygen quotient of the Stromboli lava, No. IX, also corresponds closely with that of a mixture of labradorite and aluminous augite, and in outward appearance it resembles the lava of Ætna, although it contains less labradorite and more augite in a denser basaltic matrix.

The oxygen quotient of the lava of Ferdinandia, No. X, also approximates to that of a mixture of labradorite and aluminous augite.

It is a very important fact that the oxygen quotients of these lavas should correspond to that of true dolerite, a rock whose chief constituents are labradorite and aluminous augite. The more this differs from the normal value of 0·60, as in the latter two, the more reason there is for inferring the presence of other foreign constituents. The reason why this relation prevails, especially in lava, is evidently that these volcanic products of such recent date still retain their original composition. When these lavas shall have attained the age of dolerite rocks, their composition will have become altered, as it is in those rocks, and it will then be difficult to determine their original composition. It cannot be a mere accident that lavas, or those doleritic rocks that are least altered, are anhydrous, while other doleritic rocks contain a greater or less amount of water in proportion to the extent to which their composition differs from the original and normal composition.

In conclusion, I may mention as an example of a highly decomposed augitic rock a melaphyr from a dyke in the muschelkalk, near Gnettstadt, in the Steigerwald. The mass is almost grey, in some places green or black, with isolated dark red patches; effervesces slightly with acids. It contains, in a black matrix, augite, hornblende, and calc-spar, and according to v. Bibon's analysis, consists of—

Silica	29·85
Alumina	9·22
Peroxide of iron	15·14
Lime	3·54
Magnesia	2·25
Chloride of sodium	0·99
Carbonate of lime	21·30
„ magnesia	14·41
Sulphuric acid	trace
Water	4·30
	101·00
O. Q.	0·692

The small amount of silica, the total absence of alkalies, the large amount of carbonates and of water, and the fact that hydrochloric acid decomposes 78 per cent. of the rock, all indicate the very advanced stage of decomposition which, if this rock was originally melaphyr, has chiefly affected the labradorite. The large amounts of lime and magnesia, indicated by the reduction of the analysis, admit of the inference that the greater part of these earths do not originate from the decomposition of silicates in the rock, but have been introduced from the muschelkalk. This is the more probable from the occurrence of spherical masses of arragonite, and sometimes calc-spar, between the tilted strata of muschelkalk. Deducting the carbonates as foreign constituents, the oxygen quotient approximates to that of melaphyr. This, however, is assuming that the rock has received 40 per cent. of carbonates, and that a corresponding amount of its constituents have been removed. These carbonates appear to have displaced the labradorite.

C. BASALT.

With regard to the occurrence of basaltic cones and volcanoes, the crater ridges and peaks in the Eifel, v. Dechen has pointed out the very important fact that there is a definite relation between their height and that of the surrounding grauwacke limestone, or variegated sandstone rocks that are penetrated. The highest basaltic mountains and crater ridges are situated at the highest points of the level ground. At the average levels the several peaks rise only to the same height above it; and where the surface presents hollows lower than the bottom of the present valley, the height of the mountains of basalt and scoriæ is less, and they do not rise higher above the adjoining plains than in the higher regions.[*]

Thus the highest basaltic cone in the Eifel, the Hohe Acht, which is 2,340 feet above the level of the sea, rises 220 feet above the grauwacke. Not very far from it, near Kaltenborn, the grauwacke rises pretty uniformly on all sides to a lofty peak, at the summit of which is the Kaltenborn head, a basaltic cone about 100 feet high. The Mosenberg, 1,626 feet above the level of the sea, the most perfect of the extinct volcanoes of the Eifel, with its four craters, rises 250 to 300 feet above the grauwacke plateau. Near the village of Gees there is a basaltic peak rising about 100 feet above the variegated sandstone. The Falkenley, near Bertrich, is 1,276 feet high, and rises 82 feet above the grauwacke.

This scoriaceous cone, the Hüstchen, 1,262 feet high, with a walled crater, and the Tümmelbusch, a basaltic crag, are situated only 1,900 to 2,500 feet sidewards from the Uesbach valley, which is 700 feet deep.

It is very remarkable that these volcanic eruptions have taken place so near to the valley, and have penetrated the thicker mass, while there was close at hand, a shorter and easier outlet, and that the volcanic fissure upon which they are situated has not protruded from the surface in the Uesbach valley. This remarkable fact is to be observed everywhere in the Eifel, though in a less marked degree than at the above-named locality.

It cannot be assumed that these volcanic eruptions took place prior to the formation of the valleys; for in the Uesbach valley there is between Bertrich and the Falkenkaul a wall of the same columnar basaltic as that which occurs upon the height, and passes into the scoria. This basalt has exactly the appearance of being the remains of a lava stream that has flowed down into the valley, and has been partially destroyed by the continuous action of water. The lava streams of the Mosenberg, of the crater near Gerolstein, of the scoriaceous mountains in the valley of Hohenfels, etc., also extend down into the valleys. Consequently, these valleys existed prior to the eruptions.

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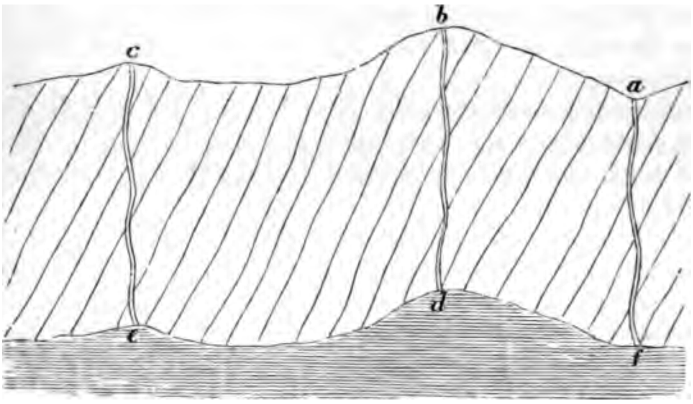
[*] Geognost. Uebersicht der Umgegend Bertrichs, in "das Bad Bertrich," 1847, p. 25.

Whatever may have been the force by which lava has certainly, and basalt has probably, been protruded, the relation between its action and the height of the strata which form the base of the cones is difficult to comprehend. Some approximation to this might be made, if it could be assumed that the configuration of the under surface of the strata corresponds with the upper surface, and is bounded by a melted mass, as is shown in the accompanying section. Such a parallelism of the upper and under surfaces must prevail to some extent; for if the undulation of the grauwacke is the result of unequal elevation, the convexity of the upper surface must correspond with the concavity of the under surface. The concavity of the upper surface that has been produced by the cutting of valleys, as at *a*, would not of course have any corresponding convexity of the under surface.



Supposing, therefore, the grauwacke to be, as it were, floating upon the melted mass, like ice upon the sea, this melted mass would be higher at *d* and *e* than at other points of the under surface of the grauwacke, and it would rise through the fissure *d b* as high as it would through the fissure *e c*. Thus, for instance, the convexity at *b* would represent the Hohe Acht, and that at *c* the Falkenley near Bertrich. The same force that raised the melted mass to 1,276 feet above the level of the sea at *c* would have raised it 1,064 feet higher at *b*. Under the assumed conditions it would be quite intelligible that both eruptions might have taken place simultaneously under the influence of the same force.

The protrusion of lava, etc., presupposes the existence of a fissure extending to a depth where there is melted material; for the force which raises it cannot have produced a channel of very considerable depth, just as a bullet penetrates a board. Fissures in the grauwacke, varying in width from the thickness of paper to several feet, are so remarkably frequent, that it is often possible to find ten or twelve within a distance of a few inches. By far the greater number of these are filled with quartz, and very rarely with metalliferous minerals or crystalline rock masses. Supposing an open fissure, such as that containing the quartz dyke, 17 feet thick, in the grauwacke near Liers, above Altenahr, to extend from the surface down to the point where there is melted material, it is evident that within a short space of time enough of the melted material might be forced up as would form a very considerable basaltic cone or lava stream. If these conditions had existed, there can be no doubt that this fissure would have been filled with lava within a very short time, instead of having been filled with quartz in the wet way by a process that occupied an enormous length of time.

If the force by which lava is raised is decidedly that of water vapour,* it is only necessary to suppose that water penetrated between the tilted strata of the grauwacke and clay-slate to the points *e* and *d*. Being there converted into steam of high tension, the force thus exerted upon the melted mass would tend to elevate it through the fissures.

This view of the protrusion of lava may, perhaps, serve to elucidate the remarkable circumstance pointed out by v. Dechen, and to show why the volcanic eruptions in the vicinity of valleys have made their appearance at the more elevated points. If, in consequence of an earthquake, or any other analogous cause, a fissure were opened in the valley cut at *a*, which extended down as far as the volcanic focus, the water of the brook flowing through this valley would discharge itself into the fissure, and have been converted into steam. This steam would have exerted pressure upon the melted mass at *f* to an extent corresponding to the pressure of the column of water in the fissure *a f*. The melted mass could not have been forced up through this fissure, but the force of the steam might have raised a column of lava corresponding to that column of water in another fissure, for instance in *d b*. Thus it would be intelligible why the lava has risen to the more elevated points, traversing thicker masses of rock instead of taking the shortest outlet.

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* G. Bischof.—Researches on the Internal Heat of the Globe, p. 209.

Assuming that the temperature increases uniformly towards the interior of the earth, in the same proportion as is observed within accessible depths, lava would be in a state of fusion at a depth of from 5 to 5½ geographical miles.* Taking into account the great inclination of the grauwacke strata, it may be supposed that a part of these strata, 5·3 miles long, was situated like an inclined plane, one end being depressed 2·5 miles deep, and the other end elevated to the same extent; such a portion would then, with an inclination of 70°, which the grauwacke strata present, have a thickness of five miles, and according to the above assumption, the lower end would be in contact with melted lava. Therefore it is easy to comprehend the possibility that the inclined strata of grauwacke may extend to the volcanic focus, and that the melted masses of the Eifel volcanoes can only have been forced up through fissures in this rock by the force of steam. Since we find only fragments of grauwacke and clay-slate imbedded in the scoriæ of these volcanoes, this circumstance is in favour of the opinion that these fissures are situated entirely in the transition rocks.†

So long as we have no satisfactory views as to the above-mentioned connection between the height of the basaltic cones and volcanoes of the Eifel and the height of the rocks which constitute their base, and no sufficient explanation why the volcanic eruptions appear at the greatest heights, our views with regard to the eruptive nature of basalt, etc., will be imperfect.

There can be no doubt that the basaltic cones of the present day project to a greater height above the rocks constituting their base than they did at the time of their protrusion, for the latter rocks, especially clay-slate, are much more liable to mechanical disintegration by water than basalt. On the road from Adenau to the Hohe Acht there are a great number of very large blocks of quartz scattered over a large area called the Steinig Rotter. These undoubtedly originate from quartz dykes, the adjoining rocks of which have been washed away. The above-mentioned quartz dyke, 17 feet thick, projects 35 feet above the grauwacke. This shows to what an extent the surface of the grauwacke may be lowered by weathering and the removal of the disintegrated portions during a long period, for the quartz, which is much less liable to disintegration, shows the minimum height to which the grauwacke formerly extended. But making due allowance for the disintegration of the quartz, we cannot in any case assume that the Hohe Acht, projecting 220 feet above the grauwacke, was at any former time entirely surrounded by that rock. If, therefore, the basalt was protruded in a melted state, it must have flowed over, and thus have formed the cone. This may, perhaps, have been the case with most basaltic cones.

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* G. Bischof.—Researches, etc. p. 210.

† The basalt of Minderberg, near Linz, contains embedded fragments resembling granite.

Since we find in the Eifel, masses which, like the scoriæ, rapilli, etc., bear the unmistakeable impress of volcanic origin, with craters sometimes surrounded with scoriæ, others open at one side, where lava has flowed out of them, which may be traced for a mile and more; since all the phenomena are the same as those presented by volcanoes that are still active, it remains only to show that there is a transition of lava into basalt, in order to infer with great probability that the latter as well as the former is of igneous origin. v. Dechen describes the two volcanic cones near Bertrich, the Falkenley, and the Facherhöhe, as being covered with scoriæ, which show by their form that they were once liquid, and being projected in this state into the air solidified as they fell. The fragments present the greatest diversity of form, and they contain throughout small crystals of augite that are sometimes quite sharp. Large rocks projecting from the craters of the Facherhöhe and the Hüstchen, alternately present scoriaceous, porous, and vesicular characters, or are compact and similar to basalt. Augite and olivine are the only constituents that are mineralogically recognizable. The latter is especially characteristic of basalt, and therefore it is admissible to call this rock basaltic. In these rocks there are a number of imbedded fragments of grauwacke and slate, often of a brick-red colour, vesicular at the edges, and gradually blending with the surrounding scoriæ, together with fragments of white quartz, sometimes unaltered, sometimes altered at the edges; fragments of felspar presenting indications of incipient fusion and vesicular patches, and pieces of a compact or vesicular vitreous substance.* The scoriaceous mass of the mountain, which is probably 160 feet high, and is for the most part exposed, constituting a precipitous crag, gradually passes at the lower part into a compact lava, containing a large quantity of olivine, and separated into irregular thick columns, which have sometimes so little porosity that they cannot be distinguished from true compact basalt.

The basaltic streams, their connection with craters, their compact or scoriaceous character, in the one case at the surface, in the other at the lower portion, corresponding perfectly with true basalt, admit of no doubt as to their igneous origin.

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* Leonhard.—Die Basalt Gebilde, p. 391.

In the Eifel, basaltic streams are met with principally at the volcanoes near Gerolstein and the Mosenberg. At the former place they may be traced along the valley between lofty limestone and dolomite rocks as far as the Kyll river. On both sides of the valley there are small basaltic cones, and the incline of the valley is so slight that large masses of dolomite could not have been carried down by water. The rock here is rich in olivine, and resembles true basalt, except in being sometimes rather more porous.

The basaltic stream at the Mosenberg has issued from an opening in the last of the four craters at the south-eastern side of the mountain, and extends as far as the Kyll brook, the course of which has been somewhat altered by it. On the opposite side of the brook there are a great number of basaltic blocks, situated high upon the clay-slate, the remains of the end of the stream where it intersected the brook. As at Gerolstein, it is impossible to suppose that blocks of basalt can have been carried down the valley by water, and upon the heights on each side of the valley there is not any basalt. Here and there the basaltic masses form continuous ranges of hills. The rock contains olivine, and presents such uniformity of character at all parts that there can be no doubt as to their common origin. At the upper and lower end of the stream the mass is rather more porous or more compact, and at the lower end scoriæ alternate with the compact mass. Above this long stream there is another shorter one, which terminates near the commencement of the former; this has not flowed from a crater opening, but apparently from a lateral opening in the third crater. A projecting rock, which appears to stand upon a fissure in the scoriaceous wall of the crater, represents the commencement of this stream, the mass of which corresponds exactly with that of the longer stream.

Besides these basaltic streams, which have undoubtedly flowed from craters, there are innumerable others the origin of which cannot be traced to craters at all, or with any certainty. Among those which I have examined are those at the Bickeberg, the Alterfass, the Weissley, which enclose the valley of Hohenfels; the broad stream that extends from the Errensberg to Dockweiler and Dreis, as well as the basaltic masses on the left declivity of the Lyfer, near Daun, which cover a slightly-inclined area much exceeding a hundred morgen. They are situated on the declivities of basaltic mountains, and may often be traced for considerable distances along the valleys. These declivities are in some instances so slight that solid blocks could not have rolled down them. The regular distribution of these blocks of basalt, although with many interruptions, differs widely from the irregular situation of the masses that have rolled down steep declivities, so that they cannot have reached their present position in this way, or have been carried by water. In addition to this the occurrence of masses of scoriæ, alternating with the basaltic rocks, and of thick beds of rapilli and volcanic sand in their immediate vicinity, indicates with certainty that eruptions have taken place, even where craters cannot be recognized. The mass of these streams has in general the same character, containing much olivine, and being more or less porous or compact.

The situation of these streams in the valleys, and overlying grauwacke on the declivities, and the detrital masses in the valleys, shows that they flowed along the valleys, and that since that time the general configuration of the surface has been but little altered. All these circumstances show that there can be no doubt as to the igneous origin of basaltic rocks.

The ascent of lava in fissures is an established fact; and if the production of basaltic rocks from lava can be admitted to take place, nothing can be said against the opinion that dykes are in thi way filled with such rocks. If Friesleben's[*] remark, that basal almost always occurs in very wide fissures, were generally applicable, there would be little difficulty in comprehending that such fissures were filled by melted material. But instances are known in which basaltic veins are very thin. Thus, in Anglesea, the rocks are traversed in all directions by basaltic veins only a few inches thick. The trap veins in Ireland vary in thickness from a few inches to several hundred feet.[†] In the island of Barra, thin veins of black fine-grained basalt run out into branches of extreme tenuity, which are variously interwoven, traversing both the gneiss and the granitic dykes in it. All these veins present sharply defined lines of contact with the adjoining rock, and only those which are exposed to the atmosphere present a resemblance to tuff. At some places this net-work of basaltic veins is so abundant that the gneiss and granite are separated into small and irregular fragments, giving the mass the appearance of a conglomerate. Similar phenomena are presented in the islands to the south of Barra.* Round Sleat, in Skye,† trap dykes frequently traverse the gneiss, and at Loch Eishort, the sandstone. The latter are very thick and may often be traced to the surface of the lias strata. These dykes are intersected by others of much less thickness, frequently only half an inch, and consisting of a very compact, hard, black basalt, which sometimes resembles pitchstone. These veins are much less frequent than the thicker ones, and they are very numerous, only round Garsven and Kornisk.

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[*] v. Moll's Jahresb. iv, 62.

[†] Berger.—Transact. of the Geol. Soc., iii, 226.

The impossibility of granite being forced in a melted state into narrow fissures has already been pointed out.‡ There is, certainly, a great difference between it and basalt, as regards fusibility; and the results of experiments with melted basalt show that it would soon solidify when forced in a narrow fissure of a rock at the ordinary temperaature. Nor can we assume that the lava or basalt had a temperature very much higher than its melting-point, for, independent of the presence of imbedded fragments of clay-slate and olivine, it sometimes contains fragments of felspar and quartz, so that the temperature must have been below that of a porcelain kiln, and even insufficient to make it act as a flux, although the combination of protoxide of iron and silica takes place so readily. However, it is certain that basalt may be of igneous origin, and therefore it is possible that conditions prevailed which admitted of the injection of these thin veins.

Even in the case of the thicker basaltic dykes, especially those which appear as layers between sedimentary strata, there are often serious difficulties in accounting for their origin.

Independent of the geognostic evidence of the igneous origin of basalt, or of rocks consisting of augite and labradorite generally, there are other kinds of evidence to the same effect.

In most meteoric masses olivine occurs; the dark-coloured mineral they contain seems to be augite rather than hornblende. Rammelsberg § calculates that most meteoric stones may be regarded as mixtures of olivine, augite, and labradorite; and since they fall upon the earth red-hot, it can only be supposed that they are of igneous origin. Hence, it is not unimportant to find that they contain the constituents of basalt.

Mitscherlich showed that in smelting copper at Fahlun, slags are produced, which consist of bisilicates, and present the crystalline form of the augite in basalt or in lava. Berthier and Mitscherlich melted in the porcelain kiln, mixtures of silica, lime, and magnesia, in the proportion for producing bisilicates, and obtained, by gradual cooling, a mass that had a cleavage corresponding to that of augite, and contained perfect augite crystals in a cavity.*

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* Macculloch.—Western Islands, i, 83.

† Ibid. p. 395.

‡ See ante, p. 52.

§ Handwörterb, 2nd Suppl., p. 91.

Rammelsberg's † analyses of the crystallized slags from the iron-smelting works at Mägdesprung, show that, assuming alumina to be capable of replacing silica, the crystals they contain have generally the composition of augite. Calculating the oxygen quotient as for aluminous augite, it is found to vary from 0·669 to 0·895. The crystalline form, moreover, does not appear to be that of augite.

	I.	II.	III.	IV.
Silica	48·88	52·96	51·69	45·52
Alumina	10·88	16·46	12·06	17·72
Magnetic oxide of iron	11·65	5·32	..	7·69
Protoxide of iron	..	2·82	12·39	7·17
Peroxide of iron	2·57	..	5·13	..
Sesquioxide of manganese	0·09	..	..	..
Lime	11·30	8·79	6·35	11·15
Magnesia	4·86	9·32	7·65	6·04
Soda	3·61	3·60	2·27	3·08
Potash	2·66	1·19	2·45	1·63
Titanic acid	2·84	..	..	..
	99·34	100·46	99·99	100·00
O. Q.	0·639	..	0·585	0·696
After deducting the magnetic oxide of iron	0·531	0.565	..	..
After deducting both it and the titanic acid	0·487	..	..	..

Analysed by

I. Basalt from the neighbourhood of Weltzlar } C. G. Gmelin.‡

The constituents of this rock are not described. It presented a very marked weathered crust of a blueish grey, or pale yellow colour. The comparative examination of the weathered and unaltered rock showed that the former contained considerably less gelatinizing substance; and in the gelatinizing portion the amounts of silica, titanic acid, lime, magnesia, and alkalies were much reduced, while that of peroxide of iron was much increased, the iron having been rendered insoluble by peroxidation while the other constituents were abstracted by water.

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* Annal. de Chem. et de Phys., xxiv, 376.

† Poggend. Annal. lxxiii, 95. ‡ Leonhard.—Basalt Gebilde, i, 269.

	Analysed by
II. Basalt, containing olivine, from Meissner	Girard.*
III. Basalt from the Steinsburg, near Suhl	Petersen.†
IV. Basalt from Stolpen	Sinding.‡

This rock contains olivine, not only as detached crystals, but also disseminated through the entire mass.

	V A.	V B.	VI.	VII.	VIII.
Silica	44·90	46·68	43·71	44·5	32·50
Alumina	18·71	18·25	10·30	16·75	15·75
Magnetic oxide of iron.. ..	..	..	10·79	..	25·00
Protoxide of iron	9·09	8·93	3·57	20·00	..
Sesquioxide of manganese ..	..	..	1·18	0·12	..
Lime	12·90	10·64	15·08	9·50	10·82
Magnesia	7·14	10·32	12·33	2·25	4·89
Strontia	..	..	0·08	..	..
Soda	6·58	4·40	2·16	2·60	4·90
Potash	0·68	0·78	0·80	..	1·11
Water	..	..	..	2	3·50
Loss	..	..	..	..	1·53
	100·00	100·00	100·00	97·72	100·00
O. Q.	0·816	0·775	0·692	0·784	1·235

V. Basalt from Wickenstein, near Querbach (Lower Silesia) A. Löwe.§ B. Girard.‖

It contains rather large crystals of black augite, and granules of magnetic oxide of iron; the former being very distinct at the weathered surface, where the greyish earthy matrix had been washed away. Girard states that this rock is quite free from olivine.

VI. Basalt from Stettin C. G. Gmelin.¶

VII. Basalt from Hasenberg, near Libochowitz (Bohemia) Klaproth.**

This rock is stated to contain particles of hornblende intimately mixed with the matrix, and but very few granules of olivine. It was, also, found to contain a carbonaceous substance.

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* Poggend. Ann. liv, 562.

† Rammelsberg.—Handwörterb. i, 84.

‡ Poggend Ann. xlvii, 182.

§ Ibid. xxxviii, 151.

‖ Ibid. liv, 557.

¶ Op. cit. p. 266.

** Beiträge, iii, 245.

The presence of such substances is by no means conclusive evidence that rocks are not of igneous origin, because it is very possible that they may be introduced by water. But it is not the less certain that the water which introduced organic substance into basalt, may also remove inorganic substance, and that in this way chemical alteration may take place even in so compact a rock as basalt.

Analysed by

VIII. Basalt from Grosswallstadt, near Aschaffenburg } v. Bibra.*

This rock underlies variegated sandstone, and at one place where they are in contact the sandstone is columnar. The basalt is very hard, greyish-black, containing crystals of augite, hornblende, and zeolites.

IX. Basalt from Crouset (Haute Loire) Ebelmen.†

A rounded fragment, compact and sound at the centre, decomposed to the depth of 7 or 8 millimetres at the surface. The sound portion contained olivine, the decomposed portion did not.

A. sound basalt; B. altered portion.

	IX A.	IX B.	X A.	X B.	XI A.	XI B.	XI C.
Silica	46·1 ‡	36·1	53·0	58·1	43·4‡	43·0	42·5
Alumina	13·2	30·5	18·4	22·6	12·2	13·9	17·9
Protoxide of iron ..	16·6	..	9·5	..	12·1	8.3	..
Peroxide of iron ..	..	4·3	..	4·0	3·5	5·4	11·5
Lime	7·3	8·9	6·8	2·9	11·3	12·1	2·5
Magnesia	7·0	0·6	3·5	2·2	9·1	7·3	3·3
Soda	2·7	0·9	3·1	3·3	2·7	0·5	0·2
Potash	1·8	0·6	2·7	2·7	0·8		
Oxide of titanium ..	..	0·6	..	..	..	..	..
Water	4·9	16·9§	3·7	3·5§	4·4	9·5	20·4
	99·6	99·4	100·7	99·3	99·5	100·0	98·3
O. Q... ..	0·653	0·909	0·555	0·489	0·755	0·730	0·627

X. Basalt from Polignac (Haute Loire) Ebelmen.

Greyish, earthy, mixed with some magnetic oxide of iron. White and friable at the surface. A. sound; B. altered.

XI. Basalt from Kammerbühl, near Eger Ebelmen.

The decomposition of this rock commences with the separa-

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[*] Journ. für prakt. Chem. xiv, 413.

[†] Comptes Rendus, xx, 1415. See also my remarks in the Jahrb. für Mineral. etc., 1847, p. 714.

[‡] With traces of titanium.

[§] With organic substance.

tion of globular masses that are gradually altered from the surface to the centre. A. sound; B. and C. altered.

	XII.	XII A.	XIII A.	XIII B.
Silica	37·43	44·10	46·4	49·6
Alumina	13·16	15·51	21·7	25·9
Protoxide of iron	1·23	12·01	20·2	13·1
Peroxide of iron	..	..	1·1	0·6
Magnetic oxide of iron..	7·50	8·84	..	..
Lime	7·20	13·73	..	..
Magnesia	2·32	3·39	10·8	10·0
Soda	2·06	2·42	..	..
Potash	..	..	..	..
Carbonate of iron	14·60	..	..	..
" lime	7·90	..	..	..
" magnesia	1·15	..	..	..
Water	6·09	..	..	..
	100.64	100·00	100·2	99·2
O. Q..		0·688	0·794	0·741

Analysed by

XII. Basalt from Ober-Cassel, near Bonn. Bergemann.*

Greyish-black, compact, uniform, not affected by the magnet. Appears not to contain true zeolitic minerals, and but little olivine. It contains much carbonate of lime, and many fine calc-spar crystals. After treatment with acids there remains a bright green mass with white spots, and rendered porous by the extraction of carbonates. There are, here and there, a few particles of black augite, and hydrochloric acid separates from the coarse powder a number of small transparent and colourless laminæ of labradorite.

XII A. The same analysis reduced.

XIII A. A highly-decomposed basalt from a dyke in the Virneberg copper mine, near Rheinbreitbach } R. Rhodius.†

This basaltic dyke is intersected at many places by lodes bearing copper ores, and it is particularly remarkable from the fact, that at the points of contact with the lodes the decomposed basalt is traversed by thin laminæ of metallic copper. The decomposed rock resembles a greenish-gray bole.

XIII B. Another piece of the same rock.

The decomposed basalt consists of a greyish matrix, with innumerable small greenish particles, presenting some indications of augite form, here and there, and often containing a greyish nucleus. Sometimes they are hollow. There can be little doubt that the matrix is decomposed labradorite, and the greenish particles decomposed augite, similar to the green earth of the Fassathal.*

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* Op. cit. p. 38.

† Liebig's Ann. lxiii, 212. See also Nöggerath—n. Jahrb. 1846, p. 457.

XIV A.

		Potash.	Soda.
Dissolved by hydrochloric acid.. ..	26·40	0·24	1·49
Residue	73·60	0·16	1·05
	100·00	0·40	2·54

XIV B.

		Potash.	Soda.
Dissolved by hydrochloric acid.. ..	18·33	0·14	0·53
Residue	81·67	0·28	1·26
	100·00	0·42	1·79

XIV C.

		Potash.	Soda.
Dissolved by hydrochloric acid.. ..	16·67	0·06	0·18
Residue	83·29	0·29	1·44
	99·96	0·35	1·62

	Analysed by
XIV A. Basalt from Ober-Cassel, near Bonn	C. Bischof.†
XIV B. The same rock, somewhat decomposed	
XIV C. Basaltic earth, resulting from complete decomposition	

The amount of silica, and the oxygen quotient of the rocks

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* English edition, ii, 328.

† De Alcalibus in Plantis. Bonnæ, 1848.

I, II, and III, show that they consist either of a mixture of aluminous augite with labradorite, from which the bases have been partially extracted, or else of labradorite and augite without alumina. The latter view is least probable, since the augite from basaltic rocks has always been found to contain alumina.*

Magnetic oxide of iron was recognizable in I, and was probably present in II. By deducting it from the basalt, No. IV, the amount of silica is increased to 49·31 per cent. This and the oxygen quotient correspond tolerably with a mixture of labradorite and augite without alumina. If the olivine present in this basalt could also be deducted, the oxygen quotient would be somewhat reduced, and approximate still more to the normal value.

The amount of silica and the oxygen quotient of V. A, and B, do not admit of the opinion that the rock consists only of augite, labradorite, and magnetic oxide of iron, unless a portion of the silica has been removed by water. Girard considers that it consists of augite, containing a small amount of silica, with nephelin, and mesolite. The presence of nephelin may be indicated by the fatty lustre, and this may also indicate a connection in composition between this basalt and the nephelin dolerite, which always occurs in districts where there are basaltic rocks. The presence of nephelin would reduce the amount of silica and increase the oxygen quotient. If, at the same time, acids extract the whole of the alkalies, as in the case of the rock analyzed by Löwe and Girard, the presence of nephelin is still more probable. Still, as some labradorite is decomposed by acids, their action upon basalt is not decisive evidence of the absence or presence of these two minerals.

Gmelin considers that the peroxide of iron, extracted from the basalt VI, represents magnetic oxide of iron; and, deducting it, the amount of silica becomes 49 per cent. In this case, it might be regarded as a mixture of aluminous augite with labradorite. The small amount of alkalies seems, nevertheless, to point to an advanced decomposition of the labradorite which must have been accompanied with separation of silica.

The unusually large amount of peroxide of iron in the basalt, VII, shows that a large portion of it must originate from magnetic oxide of iron and olivine. Klaproth's analysis does not afford any means of determining the constituents of this basalt, but it probably consists of aluminous augite, labradorite, magnetic oxide of iron, and olivine.

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* English edition, ii, 312.

The composition of the rock, VIII, differs so much from that of basalt, or the augitic labradorite rocks generally, that, notwithstanding the presence of augite, it cannot be regarded as true basalt. Since it does not contain any magnetic oxide of iron, since the amount of silica is less than that in nephelin, and since the oxygen of the bases exceeds that of the silica, the anomalous composition of this rock cannot be ascribed to the presence of a considerable amount of that mineral. If this rock was originally basalt, it must have undergone considerable alteration, and have lost a large amount of silica. Hence it would be interesting to know whether quartz occurs near it. The presence of zeolites, the unusual amounts of magnetic oxide of iron and of water, and also the probable presence of hornblende, also indicate considerable alteration, but a further examination of the rock, both mineralogically and chemically is very desirable.

Deducting the water from the other constituents of the basalt, IX A, the amount of silica becomes 48·68 per cent., or between the minimum and maximum of a mixture of aluminous augite and labradorite. Since, moreover, the oxygen quotient is nearly 0·667, this basalt may be regarded as such a mixture, although the presence of olivine would increase the oxygen quotient to some extent. The large amount of water in this basalt, shows that it is no longer in its original condition. From the amount of silica, and the oxygen quotient of the altered basalt, IX B, it would not appear to contain augite or labradorite. Calculating the composition of the sound and the altered basalt for a given quantity of alumina, it appears that $\frac{2}{3}$ of the silica, $\frac{1}{2}$ of the lime, $\frac{9}{10}$ of the iron, $\frac{5}{6}$ of the alkalies, and $\frac{95}{100}$ of the magnesia have been removed, or, in all, upwards of 57 per cent. of the basalt.

In any case, it appears that the decomposition of basalt may go on in such a way that more silica than bases is removed. It might be conjectured, that this removal of silica was determined by the oxidation of protosilicate of iron, since this salt is readily decomposed by oxidation. But in this instance, this action can have been but slight, for the greater portion of the protoxide of iron has been removed, and this can have taken place only as silicate or carbonate. But, if it follows from this, that the silica of basalt may be removed to a greater extent than the bases, without necessarily involving, at the same time, peroxidation of the whole amount of oxide of iron, then it follows, also, that basalt may have lost much of its silica, without the alteration being indicated by the ochrey colour, such as is so often met in the weathered surfaces of this rock. In this case, as in so many others, the decomposition of the rock, where it is exposed to the atmosphere, must be distinguished from that which takes place at greater depths, to which atmospheric influence does not extend, and where water acts either alone or together with the substances dissolved in it. It cannot be doubted that, in this case, silica might be extracted from basalt by means of water, as well as at the surface, for the oxygen and carbonic acid contained in surface-water would hinder, rather than facilitate, the solution of silica, or of a silicate. But if silica is partially removed from basalt, without the iron being at the same time peroxidized, there would be no apparent indication of the change that had taken place.

It will, therefore, be evident that a rock, in which the amount of silica is much under the minimum for an augitic labradorite rock, may, nevertheless, be basalt, provided the abstraction of silica has taken place under such circumstances, that the protoxide of iron could not be peroxided, and the alteration thereby rendered apparent. Perhaps the rock, No. VIII, has undergone such an alteration; for, comparing its composition with that of IX B, that is known to be altered basalt, it seems probable that it has originated by the alteration of basalt. The above-mentioned doleritic rock, No. VI,* may also have originated from an augitic labradorite rock, by partial elimination of silica, and conversion of greater part of the protoxide of iron, and some of the lime into carbonates.

The entire disappearance of olivine in the alteration of the basalt, IX, accounts for the considerably reduced amount of magnesia. Therefore, when an increase in the amount of magnesia is so often observed in the alteration of augite, a decrease of this constituent in the alteration of basalt cannot be wondered at, because in most instances it results from the decomposition of olivine. Moreover, carbonate of magnesia would be dissolved by the water, in consequence of the ready decomposition of olivine, and in this way the magnesia abstracted from the higher parts of a mass of basalt may give rise to the production of silicate of magnesia by the decomposition of the silicate of lime in augite and labradorite.

Deducting the water from X A, the amount of silica in the anhydrous basalt would be 54·64 per cent., very nearly as much as the maximum of a mixture consisting of aluminous augite and labradorite. Since, moreover, the oxygen quotient is much less than 0·667, and provided this basalt originally contained only these constituents, it can only be inferred that a portion of the bases have been removed. Ebelmen points out that in this case also, calculating the composition of the unaltered and altered basalt for a given quantity of alumina, it appears that a considerable portion of the silica, with almost two-thirds of the lime, magnesia, and iron, have been removed, and that the alkalies exist in both substances in the same proportion. In this instance, the decomposition of the augitic portion appears to have preceded that of the labradoritic matrix.

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* See ante, p. 234.

The partial loss of bases which, according to the comparison of X A with X B, has taken place during the alteration, must have taken place in the case of what is regarded as the original basalt. It is certainly not unimportant, that from the amount of silica, and the oxygen quotient of X A, a partial loss of bases may be inferred, which took place at a later period.

But it may be asked, how is it that basalt is sometimes altered by loss of silica, sometimes by loss of bases? This seems to be merely owing to circumstances determining the decomposition of labradorite before augite, or the contrary.

The decomposition of augite is effected, independently of reaction with mineral substances in water, by carbonic acid and oxygen, either by contact with the atmosphere or with surface water, because it contains oxides that are capable of higher oxidation. Labradorite, on the contrary, contains only small quantities of protoxide of iron and manganese, and, independent of the action of mineral substances in water, would be decomposed chiefly by the carbonic acid. Therefore, in the case of an augitic labradorite rock exposed to the joint action of carbonic acid and oxygen, there is a greater opportunity for the decomposition of augite than when it is acted upon by carbonic acid alone. Under such conditions it may be decomposed before the labradorite, and this would be still more probable if the action of carbonic acid were quite excluded. But besides the action of water, there are a number of other circumstances which may be supposed to determine the decomposition of augite or labradorite.

In the case of the basalt, No. X, the decomposing action of carbonic acid preponderated over that of oxygen, for less than half the protoxide of iron remains as hydrated peroxide, the remainder having been removed as carbonate. This agrees with the fact that the basalt is covered with a white pulverulent crust, for the less hydrated peroxide of iron there is left in the rock, the less possibility is there of its being brown coloured. The analysis of this crust, X B, shows, moreover, that it has the composition of a slightly-altered labradorite, with remains of decomposed augite. Probably the magnetic oxide of iron in this crust is a product of the decomposition of augite.

In the case of the basalt, No. IX, the conditions are similar; three-fourths of the protoxide of iron have been removed, and only one-fourth remains as hydrated peroxide.

Besides the differences in the decomposition of basalt, resulting from external circumstances, there are other differences dependent upon the composition of the rock.

One of the alterations of augite results in an increase of the amount of silica, as in its conversion into uralite, asbestos, steatite, cimolite, and opal. This agrees with the fact that in the basalt, No. X B, where the augitic constituent only has been decomposed, there is a relative increase of silica.

Deducting the water from the other constituents of No. XI A, the amount of silica in the anhydrous basalt appears as 45·64 per cent.; and as the oxygen quotient is more than 0·667, it follows that, if this basalt originally consisted of labradorite and aluminous augite, some silica must have been removed.

In XI B the proportion of oxygen in the bases to that in the silica is less than in XI A, but it is uncertain whether the diminution of bases has been accompanied by a diminution of silica in any degree. In the decomposition of this basalt, oxygen appears to have exercised a considerable share, for in XI C we find the whole or greater part of the iron.

When in the decomposition of the labradorite in basalt, silica is eliminated, and in the decomposition of the augite the amount of silica is relatively increased, it may happen that these two processes compensate each other, so that considerable alteration may have taken place which is not recognizable by a comparison of the relative amounts of silica in the altered and unaltered rock.

The oxygen quotient of the basalt, No. XII, after reducing the analysis, does not much exceed the normal value for a mixture of aluminous augite and labradorite, and deducting the magnetic oxide of iron, the amount of silica is 48·38 per cent. Moreover, by the treatment with acid, the presence of these minerals is recognizable. The large amount of carbonate of iron agrees with Ebelmen's analyses, which show that in the decomposition of basalt, considerable quantities of iron are removed as carbonate. If this carbonate should happen to be deposited where it previously existed as silicate, a basalt like No. XII would be produced. Such a case seems to be but seldom, for no other analysis of basalt shows so large an amount of carbonate of iron. The sound appearance of this basalt may be urged as proof that the carbonates it contains are not products of decomposition. But this is an objection that cannot be maintained. Least of all can it be supposed that carbonates were present in the basalt when it was protruded as a melted mass. The considerable amount of water, and the very small amount of soda in this basalt are especially in favour of the opinion that it has undergone alteration, and indicate a very advanced decomposition of the labradorite. Bergemann's analysis of this basalt shows, in a very striking manner, the uncertain character of the conclusions drawn from the separate analysis of the portions soluble and insoluble in acids. Deducting the carbonates from the portion dissolved by hydrochloric acid, there remain:—

Silica	76
Alumina	20
Soda	4

a composition that has not the remotest analogy to any kind of zeolite.

In the basalts, No. XIII A and B, the labradorite has been completely decomposed, and the alkalies entirely removed, together with lime and some silica. The loss of silica is indicated by the oxygen quotients exceeding 0·67, and by the amount of silica in XIII A being under the minimum. It is very remarkable, that notwithstanding the advanced decomposition of this rock, the greater part of the protoxide of iron has not been peroxidized, as is shown by the greenish gray colour of the mass.

In reference to the previously mentioned similarity between the decomposed basalts from the Virneberg, and those of the Fassathal, it may be remarked that the analyses of these rocks present the same resemblance, which would, perhaps, be still greater, if the green particles could be separated from the former. As this cannot be done, the amount of alumina is greater than in the former, but in both cases the protoxide of iron preponderates over peroxide. In the Fassathal basalt the lime is in the state of carbonate, in that of the Virneberg it has been replaced by magnesia.

The similarity between augitic lava and other basaltic rocks is the chief foundation of the opinion that the latter are of igneous origin. But the presence of water in the latter shows that if this is the case, they are no longer in their original condition. Between these rocks and augitic lava, there is, however, a chemical similarity, only in the case of those in which the oxygen quotient is at least near the value, 0·667—that corresponding to a mixture of labradorite and aluminous augite.

Bunsen* found from the analyses of six specimens of coarse-grained stratified trapp and basaltic rocks from Iceland, and of lava from Hecla, that the oxygen quotient was, in all intances, near the mean value 0·666. The composition of the great lava stream, running W. N. W. from Hecla to the shores of the Thjorsa,† that of the unaltered trapp from the island of Stromöe, that of the trapp from Fingal's Cave,‡ as well as the mean composition of the trapp rocks in the Faroe Islands, § all agree with that normal value pretty nearly. Therefore, all these rocks are to be regarded as mixtures of labradorite with aluminous augite, like lava of Ætna,‖ which corresponds very closely with that of the year 124 B.C.¶ and that of 1852.**

If the basaltic rocks that are remote from volcanoes had the same composition as those above mentioned, among which those of Ætna and Iceland are undoubtedly of volcanic origin, this would be a great support of the opinion that they also had the same origin. However, the analyses of basalt show that the oxygen quotient varies considerably, and seldom reaches 0·667. Five analyses of basalt from the Rhone, closely resembling each other in petrographic characters, give, according to E. E. Schmid,†† oxygen quotients that are all much above that of augitic lava. Therefore, the composition of these basalts is quite different from that of augitic lava, and there is no known instance in which the oxygen quotient of lava is so high as in these and other kinds of basalt.

The resemblance as regards composition between the lavas containing labradorite and augite, from such distant localities as Sicily and Iceland, is certainly remarkable, and calculated to exite surprise, that the masses of basalt which are situated so near each other as those in the Rhön district, should be so different in composition. This fact is certainly opposed to the opinion that basalt is of eruptive origin.

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* Poggend. Annal. lxxxiii, 204.

† Genth.—Ibid., p. 213.

‡ Streng.—Ibid., xc, 110.

§ Durocher.—Annal. des Mines, xix.

‖ See ante, p. 235.

¶ Joy.—Miscellan. Chemical Researches, Göttingen, 1853, p. 26.

** C. v. Hauer.—Sitzungsber. d. K. Acad. d. Wissensch. zu Wien, xi, 87.

†† Poggend. Annal. lxxxix, 303.

When a basaltic rock, consisting of augite and labradorite becomes hydrated, both these minerals combine with water, and the amount of water indicates the degree of alteration. The pseudomorphs of cimolite, green earth, and serpentine with the form of augite, show that this mineral may be converted into hydrated minerals. Labradorite is also converted into pinite, which contains 3·74. It is, therefore, quite reasonable to suppose that the anhydrous augitic and labradorite substance of rocks may undergo similar alterations, although they may not be recognizable mineralogically.

The presence of nephelin in augitic rocks has been recognized mineralogically at many places, and there is good reason for supposing that the alkalies in those rocks also belong to nephelin, which may be the case even in rocks where this mineral is not recognizable mineralogically. This is the more probable, since nephelin, like basalt, contains more soda than potash.

The essential constituents of the nephelin rock, near Löbau, are nephelin, augite, and magnetic oxide of iron.* Heidepriem † analysed this rock, and found that hot nitric acid dissolved the nephelin, olivine, and apatite completely, the augite and magnetic oxide of iron only to a small extent. After treatment with nitric acid, the residue was digested with hot hydrochloric acid which dissolved the rest of the magnetic oxide of iron with a little of the augite.

	I.	II.	III.	IV.	V.
Silica	44·25	50·37	41·13	42·12	43·50
Alumina	24·79	5·89	14·13	14·35	32·33
Protoxide of iron	..	13·39	7·20	..	..
Peroxide of iron	2·40	..	6·61	13·12	1·42
Protoxide of manganese	..	0·17	0·06	0·18	..
Lime	5·61	19·34	12·23	13·00	3·55
Magnesia	3·38	9·45	5·33	6·14	0·11
Potash	3·53	..	1·70	2·18	5·03
Soda	9·03	..	4·38	4·11	14·13
Phosphoric acid	..	..	1·65	1·65	trace
Titanic acid	..	..	..	0·54	..
Chloride of calcium	..	..	0·04	0·04	..
Fluoride of calcium	..	..	0·27	0·27	..
Water	7·01	..	3·42	3·42	0·32
	100·00	98·61	98·35	101·12	100·39
O. Q.	..	0·466	..	..	..

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* Gumprecht.—Poggend. Annal. xlii, 174.

† Zeitschr. d. deutsch. geol. Ges. ii, 139.

I. Substance dissolved by nitric and hydrochloric acid, deducting the magnetic oxide of iron and apatite.

II. Analysis of the rock decomposed by carbonate of soda.

III. Composition of the rock as a whole, deduced from I and II.

IV. Direct analysis.

V. Composition of whitish patches in the rock.

By means of these analyses, Heidepriem calculates that the nepheline rock consists of—

Augite	45·38
Nephelin	32·61
Magnetic oxide of iron	4·00
Apatite	3·91
Titanite	1·33
Water	3·42

the deficiency of 9·35 per cent., consisting in part of the olivine dissolved by nitric acid and of a portion of the augite, also decomposed by the acid.

Heidepriem expresses surprise at the amount of water in a rock whose mineral constituents are anhydrous, especially as the rock did not present any indications of weathering, and leaves it undetermined what constituent of the rock the water belongs to. Such an uncertainty as to the significance of results obtained by the analysis of rocks will always prevail where no distinction is drawn between the alteration and weathering of a rock. Weathering consists in that kind of decomposition by which the form of a mineral is gradually destroyed, while its constituents are removed without anything being substituted in their place beyond oxygen, carbonic acid, and water. But when the decomposition of a mineral gives rise to the production of another, either with or without retention of the original form—if, for instance, tourmaline or felspar is converted into mica, the change is of an essentially different nature. Bearing this distinction in mind, there is no difficulty in accounting for the presence of water in the above rock. The nephelin it contains is as little altered as it is generally met with, for among nineteen analyses of this mineral, there are only three that do not indicate the presence of water. This shows that this mineral is especially liable to be converted into zeolites, and that it is only the perfectly anhydrous nephelin that is quite unaltered.

According to Heidepriem's experiments, the substance (I), from which magnetic oxide of iron and apatite have been deducted, could contain only nephelin; but it differs so much in composition from V, that it cannot be regarded as nephelin only. If it had originally the same composition as the substance V, it must have lost both alumina and alkalies, and have become hydrated. The composition of the substance (I) approximates to that of mesolite, if the magnesia and peroxide of iron are assigned to olivine. This would agree with the known conversion of nephelin into natrolite,* which is attended with elimination of alumina and alkalies. It is at least certain that the portion of the rock containing alkalies cannot be regarded as exclusively nephelin; it must be in part, at least, zeolitic, whether it has originated from nephelin or not.

The frequent occurrence of natrolite in cavities and fissures in basaltic amygdaloid rocks is very instructive. Since nephelin is known to be convertible into natrolite, it is probable that the substance containing alkalies, and constituting part of the matrix of basaltic rocks, which contain natrolite, is nephelin, or has the same composition. At least it is easier to account for the production of natrolite from a substance of this composition than from labradorite. Although it is very difficult to determine, from the results of analysis of basaltic rocks, what is the nature of the portion containing alkalies, it may at least be inferred, with tolerable certainty, whether this portion of the mass corresponds with nephelin or with labradorite, for the oxygen quotient of the former is 1, or, according to Scheerer, 0·889, while that of the latter is only 0·667. If, therefore, the oxygen quotient of basalt, in the cavities of which natrolite occurs, exceeds 0·667, it is probable that the portion containing alkalies has the composition of nephelin, and the natrolite has originated from it. As the oxygen quotient of anorthite is very nearly the same as that of nephelin, it may sometimes be questionable whether or not the alkaline portion of a basaltic rock has not the composition of that mineral; but this would be the case only when the analysis indicated very small quantities of alkalies, since they amount to only 0·52, or 1·85 per cent. in anorthite.

The high oxygen quotient of the basalt from the Rhöne district cannot be accounted for by the assumption that it contains nepheline and zeolites, originating from that mineral. Olivine is the only constituent recognizable, mineralogically, and it very probably contains magnetic oxide of iron. The basalt of the Kreutzberg, which has an oxygen quotient as high as 1·186, also contains the highest amount of iron and has the greatest density (3·127.) It is probable, therefore, that the oxygen quotient is principally raised by olivine and magnetic oxide of iron. The composition of the portion dissolved by acids corresponds with many zeolites, especially with thomsonite, skolezite, and natrolite, and hence the presence of nephelin may be inferred. Perhaps basalt may also contain a substance analogous to natrolite, in which, as in the iron-natrolite, a dark green mineral from Brevig,* great part of the alumina appears to be replaced by peroxide of iron.

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* English edition, ii, 145.

The masses XIV A, B, and C, show that while in the decomposition of basalt, the potash is scarcely reduced in amount, the soda is much more largely abstracted, so that in the basaltic earth there is only two-thirds as much as in the sound rock. The sounder the basalt, the greater the amount of substance dissolved by hydrochloric acid, and the reverse. This agrees with what is observed in the case of the basalt from Wetzlar, and shows that carbonated water acts upon the rock in the same manner as hydrochloric acid.

The progressive alteration of basaltic columns from the surface inwards, is very distinctly recognizable in the lower basalt quarries at the Minderberg, near Linz. Three layers of altered basalt are distinguishable, the outermost one three quarters of a line thick, ash-grey and fine-grained with brown patches; the next, brownish, eight or nine lines thick, with the olivine of a hyacinth colour, and the third, less distinct, about three lines thick, presenting a somewhat darker appearance than the unaltered basalt at the centre of the column. These three layers are not detached, but continuous, and the hardness decreases towards the surface.

Here there have been evidently two different changes going on. The ash-grey colour of the outer layer shows that iron has been partially removed; the brown colour of the underlayer shows peroxidation of the iron. It would seem that the carbonic acid in the water converted the iron in the outer crust into carbonate, which was removed, and that the water thus deprived of its carbonic acid, penetrating laterally into the basalt, oxidized the portions it afterwards came in contact with.

It is, however, remarkable, that at some parts of the interior there was a very slight effervescence with acid. This is most likely due to the existence of capillary fissures through which water penetrates more easily than through the mass of the rock.

Very different kinds of decomposition are sometimes presented by basaltic columns in close proximity. Thus, for instance, in a quarry near Dattenberg, above Linz, where the columns are remarkably long and slender, I found a row of them which appeared quite unaltered at the surface, while the adjoining row of columns were covered with an ochry coating. This was evidently due to the action of ferruginous water.

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* C. Bergemann.—Poggend. Annal. lxxxiv, 419

Basaltic boulders, upon steep declivities, rarely present ochry crusts, and the mass seldom effervesces with acids. This is probably owing to the short time the water remains in contact with them. On the contrary, in basaltic rocks, especially when situated near the bottom of a valley, water circulates continually, and perhaps stagnates sometimes, the conditions are much more favourable to decomposition. For this reason the basalt at the bottom of a quarry is frequently much decomposed, and the solid rock is found only at the upper part.

The slowness with which projecting masses of basalt are decomposed, is shown in numerous instances. Thus, at Aubenas, in the Vivarais, a very thick basaltic dyke projects thirty feet above the summit of a muschelkalk mountain. Near Arragh, in Ireland, a basaltic dyke rises like a perpendicular wall to the height of forty feet.*

By the action of acid vapour and sulphuretted hydrogen, basalt is considerably decomposed. Where sulphur veins traverse the rock, or where its surface is covered with sulphur, it may be inferred that the decomposing agent was sulphuretted hydrogen.

On the peak of the Minderberg, roots of trees are found, in which fragments of basalt appear to be imbedded. The root fibres have penetrated between the transverse fissures or joints, driving the fragments apart as they grew, and surrounding them. This is a very frequent occurrence, and shows how vegetation contributes to the degradation of rocks.

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* v. Leonhard.—Die Basalt gebilde. p. 124.

CHAPTER LV.

HORNBLENDE ROCKS.

HORNBLENDE occurs associated with all kinds of felspar; but in the rocks of which it is an essential constituent, it is, so far at least as this point can be determined mineralogically, associated either with albite—as in hornblende rocks, hornblende slate, diorite, and diorite porphyry—or with orthoclase and oligoclase—as in syenite and syenite-porphyry. However, the chemical analyses of felspar from hornblende rocks, and the analyses of these rocks themselves, show that they also contain other kinds of felspar that are particularly rich in lime.

In the dioritic or albitic hornblende rocks, the amount of albite is sometimes so small that they are almost mere hornblende rocks, and sometimes albite is altogether wanting. In others, on the contrary, the hornblende is present only in very small proportion. Among the accessory constituents of these rocks are quartz, mica, garnet, epidote, magnetic oxide of iron, and iron pyrites. In hornblende slate—amphibolite—quartz, felspar, hornblende, etc., sometimes occur in nests or as veins, and other minerals in drusy cavities. Hornblende slate occurs very frequently, and it generally presents very distinct stratification. Diorite is also of frequent occurrence as a massive rock, especially in the Ural, though it does sometimes present more or less distinct stratification. Transitions into hornblende rocks are very frequent phenomena,* so that whatever is true with regard to one rock also applies to the other.

With regard to epidote, which occurs as a parasitic mineral almost everywhere that ferruginous minerals undergo decomposition, it is met with in hornblende rocks under circumstances similar to those observed in melaphyr.† Perhaps in the former case, as well as in the latter, a similar connection between epidote and quartz exists, for in the conversion of hornblende into epidote, as it is in the decomposition of melaphyr into epidote, quartz would be eliminated.

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* Naumann.—Lehrb. d. Geognosie, i, 579, et seq.

† See ante, p. 229.

If future examination should point out the association of albite with epidote, it might be inferred that even during the alteration, albite was removed or reproduced. The possibility of this must be admitted, for I found in the Berlin collection of minerals a specimen from Arendal in which albite was seated upon epidote, and extended into cracks, while small particles were imbedded in the epidote.

It has already been remarked* that hornblende rocks rarely effervesce with acids. Even in the case of the highly-decomposed syenites or diorites of the Birkenau valley, in the Bergstrasse, effervescence with acids is a very rare character; and where it is observed, the carbonate of lime may have been derived from the overlying calcareous marl (loess). At some places the syenite contains a large amount of iron pyrites, which certainly occurs most abundantly where the rock is traversed by numerous veins of quartz, and is also imbedded in the quartz. Therefore the production of iron pyrites, and the elimination of silica, are co-ordinate phenomena, whether the quartz has originated from the decomposition of felspar, and the iron pyrites from the decomposition of hornblende, or whether the latter has furnished the material for both minerals. The effervescence with acids, of the substance between the quartz veins and the rock, observed in the case of melaphyr,† was not presented in this instance.

Besides the already-mentioned kinds of syenite and granite, there are, however, other hornblende rocks which effervesce with acids, as, for instance, that occurring in Brittany, described by Kersanton, and several kinds of diorite porphyry. In the latter, indeed, calc-spar is recognizable. The diorites near Bogoslowsk and Newionsk contain imbedded crystals of calc-spar, and they are frequently accompanied by limestone in other places.‡ In Nassau the greenstone presents all phases of alteration down to schalstone and limestone.§

In the Schönberg valley, in the Odenwald, I have observed the alteration of syenite by exposure in two very different forms. Below Elmshausen this hornblende rock appears as blocks with almost vertical cracks, and so much altered that it may be separated by the fingers into very thin laminæ, which are traversed by beads of quartz. At the same time there does not appear to be any essential difference between the composition of this rock and that of a perfectly sound hornblende rock in the immediate vicinity.

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* English edition, ii, 353.
† See ante, p. 205.
‡ Kupffer.—Poggend. Annal. xvi. 274.
§ Grandjean.—n. Jahrb. f. Mineral. 1847, p. 170.

In a rock cellar at Schönberg, situated high above the bottom of the valley, the syenite was very moist, presenting a diversity of green, brown, and yellow colours; while it was so soft that fragments could be broken away by the hand. Here and there it was converted into a steatitic mass.

Weibye[*] describes concentric layers, forming spherical masses, in the midst of the grey felspar of the syenite at the island of Lamöe. At the centre of these masses there is a crystal of thorite. Other felspar crystals contain imbedded mosandrite crystals, with similar nodular masses at the lateral faces.

It cannot be supposed that these crystals are altered felspar, for the nodular masses adhering to the thorite and mosandrite crystals present the characters of having been deposited from water, and this could not have taken place at the interior of another mineral. But if the felspar was produced after these other hydrated minerals, it cannot be of igneous origin. However the rock that now appears as syenite may have originated, it is at least certain, that after its formation the permeating water has effected the production of these zeolitic minerals in it, and afterwards of felspar. But if this felspar surrounding the hydrated minerals has been produced in the wet way, there is no ground for assuming that the entire mass of felspar in the syenite has been produced otherwise.

Nothing could prove more decisively that the water permeating rocks produces from existing materials crystalline minerals, than the above phenomenon. Thus in a solid rock the forces of chemical affinity and crystalline aggregation arrange similar molecules together, just as in a solution containing several different salts. The only difference is, that in a solution the crystals produced are more freely developed than in a solid rock, for in the former case the material is in solution, while in the latter it must first be dissolved by the water permeating the rock.[†]

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[*] n. Jahrb. f. Mineral. 1849, p. 171.

[†] In plants we find silica combined with potash, lime, and magnesia—the same substances that play so important a part in the production and alteration of rocks and minerals. In both cases we find those substances are of most importance which exist in smallest amount of water. Phosphate of lime or silica is deposited from solution in fissures just as in plants. Sulphates and chlorides,

When hornblende is converted into mica, potash must be substituted for lime. But, on the contrary, when felspar is converted into mica, magnesia and protoxide of iron must be substituted for silica. Therefore water containing potash, magnesia, and protoxide of iron, may effect both alterations simultaneously; and the water passing away may deposit lime as carbonate, and silica as quartz, in fissures or cavities at lower points, or give rise to silicification of the rock or the production of pseudomorphs.

In the case of hornblende rocks the separate analysis of the portions soluble and insoluble in acids is quite inapplicable, because their various constituent minerals are almost equally acted upon by acids. Therefore, unless the minerals can be separated, the mass must be analysed as a whole.

Any inference as to the nature of the constituent minerals of a hornblende rock from the chemical analysis can only be drawn with some degree of probability when the alkalies belong solely to the felspar; but since the hornblende containing alkalies happens to occur in syenite, and since the hornblende in globular diorite seems to contain alkalies, the determination of the constituents of these rocks cannot be made by the chemist without the aid of the mineralogist.

At first sight it might seem sufficient to make the calculation according to the formula representing the composition of the felspar occurring in hornblende rocks, the orthoclase, oligoclase, or albite. Then since orthoclase and albite differ only in the substitution of potash for soda, it would only be necessary to make use of the formulæ for orthoclase and oligoclase in the calculation. But since lime and magnesia appear to be generally substituted in some degree for alkalies in these felspars, the silica and alumina would be estimated too low if the calculation were made according to the chemical formulæ. In order to remove this error, it is necessary to determine the porportion of alkalies to silica and alumina in those felspars that have been analysed, and to obtain an average proportion in accordance with which the calculation may be made.

The formulæ deduced from the following analyses are also applicable to other crystallized rocks in which these kinds of

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which frequently preponderate in water, are not deposited to any considerable extent in plants. The presence of this preponderating amount of more soluble salts does not hinder the deposition in plants, and hence it may be inferred that it does not do so in rocks. The sulphates, chlorides, and earthy carbonates, remain in both cases in solution.

felspar occur, such, for instance, as red prophyry. With regard to hornblende rocks it will be seen that they contain species of felspar which differ considerably in composition from either orthoclase, oligoclase, or albite. So long as these species of felspar cannot be brought under a general head, data will be wanting for calculating the constituents of hornblende rocks. The amounts of oxygen in the alkalies are taken as unity below.

ORTHOCLASE.

	Oxygen of the	
	Alumina.	Silica.
St. Gotthardt	3·18	12·94
Baveno	3·21	12·64
Siberia	2·84	11·54
Martersberg, near Marienberg	3·06	13·27
Fürstenstollen, near Freiberg	3·12	12·89
Mulde, near Freiburg	2·77	11·42
Auerberg in the Harz, somewhat weathered and rather soft	3·17	13·76
Mean, excluding the felspar from Siberia and from Mulde, which are not true orthoclase	3·15	13·10

ALBITE.

	Oxygen of the	
	Alumina.	Silica.
Zöblitz	2·98	11·88
Miask,—in greenstone	2·93	11·89
Brevig, in Norway	3·09	12·24
Pantellaria	3·45	14·28
Pensylvania	3·27	12·41
Schreibershau, in the Riesengebirge	2·90	11·86
St. Gotthardt	3·27	12·72
Snarum, in Norway	3·59	13·90
Mean of these analyses	3·18	12·65

OLIGOCLASE.

	Oxygen of the Alumina.	Oxygen of the Silica.
Danvikzoll, near Stockholm	4·91	14·51
Ytterby	4·36	12·53
Arendal	3·88	11·86
Ajatakaja, north of Catharinenburg	3·54	12·19
Arendal, associated with pistacite	4·99	14·60
Schaitansk, in the Ural	4·66	14·96
Warmbrunn, in Silesia	4·75	14·25
Kimito, in Finnland	2·91	9·69
Flensburg, in Schleswig-Holstein	4·58	14·45
Tvedestrond, in Norway (sunstone)	4·63	13·26
Fürstenstollen, near Freiberg	4·88	14·40
Marienbad, in Böhmen	4·82	14·39
Teneriffe	3·73	11·72
Hammond, in New York	3·44	11·94
Boden, near Marienberg	3·59	10·90
Mont Blanc, from the protogyn	5·18	15·20
Mean, excluding the felspar from Kimito and from Mont Blanc, which differ from other oligoclase so much that they cannot be regarded as the same species.	4·34	13·28

When k represents the amount of potash, and n that of soda, in a hornblende rock,

The amount of oxygen in the potash = 0·16982 k and
" " soda = 0·25659 n.

Then, since in orthoclase the oxygen of the alumina amounts to 3·15 times, and that of the silica to 13·1 times the oxygen of both alkalies, it follows that

The oxygen of the alumina = (0·16982 k + 0·25659 n) 3·15
" " silica = (0·16982 k + 0·25659 n) 13·1

Multiplying the former of these products by $\frac{641·8}{300}$ and the latter by $\frac{577·778}{300}$ we obtain—

Alumina = (0·16982 k + 0·25659 n) 6·73
Silica = (0·16982 k + 0·25659 n) 25·23

And since in albite the oxygen of the alumina amounts to 3·18 times, and that of the silica to 12·65 times the oxygen of both the alkalies, we obtain, after multiplying by the above fractions,

Alumina = (0·16982 k + 0·25659 n) 6·80
Silica = (0·16982 k + 0·25659 n) 24·36

And lastly, since in oligoclase the oxygen of the alumina amounts to 4·34 times, and that of the silica to 13·28 times the oxygen in both alkalies, we obtain :—

$$\text{Alumina} = (0{\cdot}16982\ k + 0{\cdot}25659\ n)\ 9{\cdot}28$$
$$\text{Silica} = (0{\cdot}16982\ k + 0{\cdot}25659\ n)\ 25{\cdot}58$$

These formulæ enable us to calculate, from the amount of oxygen in the alkalies, the amount of alumina and of silica belonging to these felspars. It will be seen that the numbers obtained for the alumina and silica, according as the felspar in hornblende rock is orthoclase, albite, or oligoclase, do not differ much from each other. When the oxygen of the alkalies in these rocks amounts to 1 per cent., corresponding to from 4 to 6 per cent. of alkalies, the minimum amount of alumina is 6·73 per cent., the maximum 9·28 per cent., and the minimum amount of silica is 24·36 per cent., the maximum 25·576.

So that even when, mineralogically, it is impossible to ascertain which species of felspar is present in a hornblende rock, the errors, in the estimation of the alumina and silica belonging to them would not be much greater than those of analysis. The amount of alumina would, at the utmost, be estimated only 2·55 per cent., too high or too low, and the silica only 1·21 per cent. But even these errors would be incurred only when oligoclase was alone present, and the calculation was made according to the formulæ for orthoclase or albite, or when these two minerals were present, and the calculation was made according to the formulæ for oligoclase. This could hardly happen, because the relative proportions of the potash and soda would indicate whether potash felspar, orthoclase, or soda felspar, albite or oligoclase preponderated.

In the above analyses of orthoclase, the minimum amount of soda is 0·01, and the maximum 0·18 of the potash, excluding the felspars from Siberia and Mulde, which cannot be pure orthoclase. Consequently, when the soda in a hornblende rock exceeds the above maximum, albite or oligoclase must be associated with the orthoclase.

In the above analyses of albite, the minimum amount of potash is 0·05, and the maximum 1·1 that of the soda. Consequently, when the potash in a hornblende rock exceeds that maximum, orthoclase may be associated with albite.

In the analyses of oligoclase the minimum amount of potash is 0·04, and the maximum 0·52, of the soda, so that when the potash in a hornblende rock exceeds the maximum, it may contain orthoclase together with oligoclase.

Since, in the varieties of albite, as in oligoclase, the maximum and minimum amounts are, with one exception, nearly the same, it cannot be determined chemically whether albite or oligoclase is present in a hornblende rock.

The alkalies must of course be accurately estimated, and as hornblende rocks sometimes contain chemically combined water, the relative proportion of the oxygen in the alkalies alumina and silica will be affected, if the felspar is converted into kaolin.

Lime is not an essential constituent of orthoclase or of albite, but scarcely any specimen of albite has been found without some lime, although the amount is generally small, and seldom rises to 3·82 per cent. If it can be ascertained, mineralogically, that a hornblende rock contains only orthoclase, or only albite, the lime found in it may, without sensible error, be assigned to the hornblende. But orthoclase never occurs alone in such rocks, and is always associated with some other species of felspar.

In oligoclase lime is an essential constituent. In the above analysis of oligoclase the minimum amount is 0·03, the maximum 0·5, and the mean 0·27 of the soda, so that if a hornblende rock contained only oligoclase and 5 per cent. of alkalies, only 1·35 per cent. of lime would have to be deducted for it.

Since the amount of lime in aluminous hornblende is generally much less than that of magnesia, and is rarely equal to the latter, the relative proportion of these earths in a hornblende rock, containing felspar without lime or magnesia, would be the same as in hornblende. But in the specimens of hornblende rocks that I have analsyed, the amount of magnesia was always much less than that of lime. Consequently, these rocks must either contain a calcareous felspar, or some other mineral, such as augite, in which the amount of lime is greater than that of magnesia. The former appears to be generally the case, for, according to Delesse, the felspar of the globular diorite of Corsica contains an unusual amount of lime—12 per cent.—and the oligoclase of the syenite of the Vosges is among those which contain the largest amount of lime. On the contrary, the relative proportion of lime and magnesia in the hornblende of these rocks corresponds with the general rule that the amount of magnesia is much greater than that of lime.

These conditions obtain in all hornblende rocks in which, like those I have analysed, the amount of lime exceeds that of magnesia. Consequently, there is no doubt a class of hornblende rocks which contain a highly calcareous felspar. Taking the previous analyses of these rocks as a standard, we must infer, that such calcareous felspar occurs in them very frequently, if not universally.

When the amount of silica and alumina has been estimated by means of the formulæ for orthoclase, albite, and oligoclase, and deducted from the whole, it remains to be determined whether the silica in the residue corresponds with the composition of hornblende, or whether there is any excess. Among the analyses of hornblende the oxygen in the silica and alumina amounts to 2·5 times the oxygen in the bases, and falls as low as 2·1 times as much. But as these maximum and minimum proportions are met with only once, 2·4 times may be taken as the maximum, and 2·2 times as the minimum proportions. If, therefore, the proportion of oxygen in the silica and alumina of this residue exceeds the above maximum, it may be inferred that the rock contains free silica, and when it falls between the maximum and minimum it is uncertain whether there is any free silica or not.

A.—Globular Diorite.

This rock* occurs near Tallano, Otta, and at several points in the vicinity of Ajaccio, in Corsica. In consists chiefly of felspar and hornblende, forming sphæroidal masses in concentric or alternating layers. The central portion of these sphæroids, which is generally situated in a dioritic matrix of granular texture, has often a granitic structure; but it is sometimes coarse-grained, as near Capitello.

The felspar has a density of 2·737. It has sometimes the form of albite, but it generally appears as very thin concentric laminæ. It is not very liable to weathering, as is the case with most rocks consisting of hornblende and felspar.

The dark-green hornblende has a density of 3·08, and generally appears as small crystalline laminæ. When it is lighter coloured it is fibrous and less bright, being probably in a state of incipient conversion into asbestos. It is penetrated with laminæ of mica that can scarcely be separated. The analyses of both minerals gave the following results:—

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* Sur la diorite orbiculaire de Corse.—Annal. de Chem. et de Phys. 3, xxiv, and Mémoire sur la Constitution Min. et Chim. des Roches des Vosges. Mém. de la Soc. d'Emulation du Doubs.

	Felspar.	Hornblende.
Silica	48·62	47·88
Alumina	34·66	8·23
Oxide of chromium	..	0·50
Protoxide of iron	0·66	16·15
„ manganese	..	trace
Lime	12·02	7·05
Magnesia	0·33	18·40
Potash	1·06	0·14
Soda	2·55	0·65
Water	0·49	..
Hydrofluoric acid	..	1·00
	100 39	100·00

The felspar is regarded by Delesse as a variety of the species which he calls vosgite. The hornblende agrees in composition with the aluminous hornblende, and is very similar to that from the diorite of Kaltajuva in the Ural.

In some varieties of this diorite, which are not globular, the hornblende and mica are very frequent. The presence of iron pyrites and magnetic oxide of iron, which have been produced subsequently to the hornblende, shows that it has undergone alteration. Quartz appears rather uniformly disseminated through it, especially in the coarse-grained varieties, but only in small amount.

Delesse found the density of the powdered globular diorite 2·768, and thence calculated that it consisted of 90 per cent. felspar, and 10 per cent. hornblende. Paufert found in another specimen of globular diorite—

Silica	48 05
Lime	11·04

which would indicate 80 per cent. of felspar, and 20 per cent. hornblende. This amount of silica, compared with that of felspar and that of hornblende, shows that the rock does not contain any sensible amount of quartz.

Calculating from these data the composition of these diorites, as a whole, we obtain:—

	Diorite.	
Felspar	90	80
Hornblende	10	25
Silica	48·55	48·47
Alumina	32·02	29·37
Oxide of chromium	0·05	0·10
Protoxide of iron	2·21	3·76
Lime	11·52	11·03
Magnesia	2·14	3·94
Potash	0·97	0·88
Soda	2·36	2·17
	99·82	99·72

These analyses serve for comparison with those of other kinds of diorite, in which the felspar and hornblende cannot be analysed separately.

The felspar of this diorite appears to be either anorthite or something very like it, as will appear from a comparison with the analyses of anorthite.* A felspar very similar to that from the globular diorite was analysed by Klaproth.†

Near Pont Jean, near St. Maurice, in the Vosges, diorite occurs, the hornblende of which is very fibrous, and the felspar crystalline, whitish-green, and separable with difficulty into laminæ of a fatty lustre. It also contains a green amorphous mass of a chloritic character. Delesse‡ found the two minerals had the following composition:—

	Felspar.	Hornblende.
Silica	53·05	50·04
Alumina	28·66	8·95
Oxide of chromium	..	0·24
Protoxide of iron	0 90	9·59
„ manganese	trace	0·20
Lime	6·37	11·48
Magnesia	1·51	18·02
Potash	2·80	0·08
Soda	4·12	0·81
Loss by ignition	2·40	0·59
	99·81	100·00

This felspar agrees closely in composition with that in the melaphyr of Belfahy, § and therefore Delesse regards it as labradorite, or a variety of that species. The large amount of water and the imperfect cleavage show, however, that it is somewhat altered, for as the cleavage is destroyed in the complete conversion of felspar into kaolin, it may be supposed to be affected during the earlier stages of the alteration. The chloritic substance is very probably a product of the decomposition of hornblende.

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* English edition, ii, 214.

† Beiträge, VI. 259. Eng. edit., ii, 210, No. X.

‡ Comptes Rendus, xxx, 176.

§ See ante, 221.

This diorite appears to present an instance of the association of hornblende and labradorite; but though the composition of the felspar it contains approximates very closely to that of labradorite, G. Rose* has shown that oligoclase may be easily mistaken for that mineral. The felspar from the rock at Tyfholm's Udden, which Delesse took to be labradorite, differs from this mineral crystallographically, and since it is intimately mixed with minute laminæ of mica the analysis cannot have given correct results. Svanberg's analysis of the felspar crystals from the rhombic porphyry of southern Norway (A), and Kern's analysis of the felspar crystals from a variety of syenite near Laurvig (B), give different results.

	A.	B.
Silica	59·76	62·89
Alumina	19·60	21·24
Peroxide of iron	2·89	1·12
Lime	4·37	1·64
Magnesia	1·04	0·97
Potash	2·76	5·75
Soda	6·86	6·11
Water	1·00	..
	98·28	99·72

In A the proportion of the oxygen in the silica to that in the bases is much higher than in the felspar from Tyfholm, and this is even more the case in B, which has almost exactly the composition of oligoclase. G. Rose infers, therefore, that the latter mineral was the purest, and that if all impurities could be separated from this mineral the composition would be found to agree perfectly with that of oligoclase. However, it must be remembered that the decrease of the amount of silica may be due not only to the presence of admixtures, but also to the altered condition of the felspar, for the more advanced the conversion into kaolin, the more must the amount of silica decrease. Moreover, the production of kaolin is directly proportionate to the amount of water chemically combined with the mineral; the greater the amount of water, the smaller the amount of silica. The mineral A contains 1 per cent. of water, but the mineral B does not contain any, consequently the former felspar must contain less silica than the latter.

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* Zeitschr, d, deutsch. geol. Gesellsch. 1849, i, 378.

Hence it appears, that as a general rule in endeavouring to ascertain what species a particular felspar belongs to by means of the chemical analysis, it must never be referred to a species containing a less amount of silica than that found by analysis, but to one containing more. There is no alteration or decomposition of felspar that can result in augmentation of the amount of silica, and it is only in cases where, as in graphic granite, quartz is mixed with the felspar that a larger amount of silica will be found than belongs to the felspar. But such an admixture of quartz may be recognized mineralogically. Hence it will be seen how important it is to estimate the amount of water in minerals, and especially in felspar.

G. Rose's remarks are also confirmed in another way. The analyses of the labradorite that have been determined mineralogically show that the amount of lime is generally 12 per cent., and is seldom as low as 9·5 per cent., and that the amount of alumina varies between 28 and 30 per cent. But not only in the felspar from the rhombic porphyry, but also in that from the melaphyr analysed by Delesse;* both these earths are less, and the lime in some of them is considerably less than the above-mentioned amount. If the amount of alumina does not fall as low as the 23 per cent. in oligoclase, it must not be overlooked that a diminution of the amount of silica would be attended with a relative augmentation of the amount of alumina. The presence of water in these felspars to the extent of 2·5 per cent., and of quartz in the rock, shows that they have already lost some silica.† Accordingly, it may even be doubtful whether the rocks analysed by Delesse, and classed by him with melaphyr, are really to be regarded in this light.‡ This doubt is still more increased by the fact, that this chemist considers the dark green mineral intimately mixed with the felspar to be hornblende and not augite.

Since kaolin contains 0·1374 water, it follows that when *a* represents the amount of water in any given felspar, the amount of kaolin mixed with it will be $\frac{a}{0\cdot1374}$. Since, moreover, kaolin contains 0·4703 silica, the quantity of silica in that amount of kaolin would be $\frac{0\cdot4703}{0\cdot1347}\,a = 3\cdot423\,a$. And since orthoclase contains 0·6521 silica, the quantity contained in the orthoclase previous to its conversion into kaolin would be nearly $\frac{0\cdot6251}{0\cdot1347}\,a = 4\cdot746\,a$; consequently the silica removed from orthoclase during its partial conversion into kaolin would be: $(4\cdot746 - 3\cdot423)\,a = 1\cdot323\,a$.

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* See ante, p. 221.

† Ibid., p. 227.

‡ Ibid., p. 220.

Assuming that the same relations obtain in the conversion of oligoclase into kaolin, an amount of water equal to 2·51 per cent. in oligoclase, partially converted into kaolin, and corresponding to No. V,* would correspond with a loss of 1·323 − 2·51 = 3·32 per cent. Therefore, the original amount of silica in this felspar would have been 56·52 per cent., an amount which, though certainly less than that in oligoclase, is greater than that in labradorite.

It will be apparent that this is the only chemical mode of determining the species to which a particular felspar belongs, when the proportion of silica removed and of water introduced has been carefully estimated for each species of felspar. This investigation would lead to definite results if the kaolin from each species of felspar was a definite compound, as that from orthoclase appears to be.

It has already been pointed out that the only chemical difference between hornblende and augite is the preponderance of magnesia in the former, and of lime in the latter. It must, however, be remembered that one of the chief modes of alteration observed in augite consists in a diminution of the amount of lime and augmentation relatively or absolutely of magnesia, perhaps by a substitution of magnesia for lime. In a rock which, like melaphyr, is very liable to alteration and decomposition, and in which the conversion of the felspathic constituent into kaolin may be very far advanced, without any apparent indications of the change, it is possible that the substitution of magnesia for lime may have advanced so far that the composition of the other constituent approaches nearer to that of hornblende than to that of augite.

Comparing the analysis of the matrix of the melaphyr at Belfahy with that of the felspar from this rock, it seems probable that it contains hornblende rather than augite. For since the felspar constituted 71 per cent. of the mass, it would require 0·31 per cent. more lime than the whole mass contains, while the whole of the magnesia remains for the other constituent. But no instance is known in which augite has been found to contain magnesia without any lime, and this also seems to indicate the presence of hornblende in the above-mentioned rock. Whether this composition, corresponding to hornblende, was that of the rock originally, cannot be determined. The same result is arrived at when the composition of the matrix of the rock at Tyfholm is compared with that of the felspar in this rock. The 82 per cent. of felspar in this rock require 0·9 per cent. more lime than the rock contains, while there remains a surplus of 2·89 per cent. of magnesia, so that here again the augitic constituent appears to contain lime and no magnesia.

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* See ante, p. 221.

But if, according to the opinion of G. Rose, the rock at Tyfholm does not contain labradorite, and if, in accordance with the above considerations, there is not any augite present, it is not an augitic, but a hornblende rock.

These circumstances illustrate the points that are to be attended to, where, from the analysis of a rock it is to be determined whether or not it contains hornblende or augite, and the difficulties that may sometimes have to be met.

The following are analyses of peculiar forms of felspar that occur in hornblende rocks:—

	I.	II.	III.	IV.
Silica	58·41	56·72	52·15	59·66
Alumina	25·23	26·52	26·82	23·28
Peroxide of iron	..	0·70	1·29	1·18
Lime	6·54	9·38	9·14	5·17
Magnesia	0·41	..	1·02	0·36
Potash	..	0·80	1·79	1·74
Soda	9·39	6·19	4·64	5·61
Loss by ignition	..	..	1·75	1·02
	99·98	100·31	98·60	98·02

	Analysed by
I. Amorphous snow-white felspar, from Baumgarten, in Silesia, associated with blackish-green hornblende in a coarse-grained mixture, in which it preponderates	Varrentrap.*
II. Crystallized snow-white, translucent felspar, from the diorite porphyry of Pisoje, near Popayan, Columbia	Francis.†

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* Poggend. Annal. lii, 473.

† Ibid., p. 470.

Associated with greenish-black crystals of hornblende, generally very small, and mixed with a few granules of quartz.

	Analysed by
III. Felspar occurring as granules from the size of a pea to that of a hazel nut, in the hornblende rock, near Russgarden, in Delarne	Svanberg.*
IV. Calcareous oligoclase, from a rock near Sahla	Svanberg.†

Although the imperfect cleavage of No. I corresponds with that of albite, and although the appearance of No. II resembles that of albite, it must be admitted that these minerals do not present the least resemblance to albite in composition. If they were both altered albite they would have lost from 11 to 13 per cent. of silica, and in that case No. II could not appear translucent and bright at the cleavage surfaces. It cannot even be determined whether these felspars are altered or not, since the loss by ignition has not been estimated. It is also questionable whether No. I did not contain some potash. For the sake of comparison, the composition of hafnefjordite No. IV is added. This corresponds very clearly with No. I and II. The larger amount of lime in No. II cannot be wondered at, for the calcareous oligoclase, analysed by Forchhammer,‡ contained 9 per cent. of lime.

Although there is less correspondence between Nos. III and IV, it is not improbable that the former felspar is also a calcareous oligoclase that has lost some of its silica. The large loss by ignition shows that it is considerably altered. It is stated to be labradorite, but this is certainly an error.

B.—SYENITE.

Syenite is a massive rock. It is often traversed by dykes of fine-grained syenite, as is very characteristically shown at the Schönberg, near the Bergtrasse. Here there are masses of very hornblendic syenite, traversed by veins of very quartzose syenite, several inches thick, in all directions, so that they constitute the greater part of the rock. There would, obviously, be very great difficulty in accounting for the origin of this rock in the igneous way, and it was the examination of this rock that first shook my belief in the igneous origin of syenite.

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* Berzelius.—Jahresber, xxiii, 285.

† Ibid., xxvii, 248.

‡ English edition, ii, 201, No. XVIII.; and Journ. für prakt. Chemie, xxx, 389.

G. Rose[*] divides syenites into four classes, viz.:—

1. Consisting only of felspar and hornblende—Friedrichswærn.

2. Consisting only of felspar, oligoclase, and hornblende.—Plauenscher Grunde.

3. Consisting only of felspar, oligoclase, hornblende, green magnesian mica, and quartz, sometimes with the hornblende in very small proportion.—Radowitz, near Meissen.

4. Consisting of felspar, oligoclase, and green mica.—Polaun and Krummhübel in the Riesengebirge, and Altenberg in Saxony.

Among the accessory constituents of syenite are titanite, apatite, and magnetic oxide of iron. Epidote occurs chiefly in nests, as veins, and upon fissures in the rock. It is worth mentioning, that sometimes felspar also occurs in such cavities, and more rarely quartz.[†] Of more rare and local occurrence are zircon, nephelin, polymignite, pyrochlore, etc.

The syenite in the vicinity of Brevig, in Norway, sometimes contains black mica, which in parts displaces the hornblende, and by its presence would render the rock a granite, were it not for the absence of quartz. This syenite contains here and there zircon, pyrochlore, thorite, leucophane, elæolite, wernerite, radiolite, sulphide of molybdenum, analcime, mosandrite, a green substance resembling serpentine, etc., as accessary constituents, especially in the islands Sandöe, Oxöe, Lovöe, and Smedholmen. All these minerals occur almost exclusively in the ordinary coarse-grained syenite; in the finest-grained syenite, almost resembling sandstone, there is not any trace of these minerals.[‡]

Where the mineral constituents of the rock—hornblende and felspar—occur as large crystals, the conditions for crystallization must have been very favourable, so that other minerals could crystallize which are wanting in the fine-grained syenite. It would be interesting to ascertain whether the matrix of the latter would not on analysis be found to contain the constituents of the above-mentioned minerals, namely zirconia, glucina, cerium, etc.

Weibye[§] found in the syenite in the island of Lamöe, near Brevig, several new minerals, to which he gave the names of tritonite, catapleite, and eudnophite, and which were associated with leucophane, mosandrite, zircon, ægirine, etc. According to the analysis of Berlin, tritonite contains besides silica, alumina, protoxides of iron and manganese, lime, magnesia and soda, cerium, lauthanum, yttrium, copper, tin, and tungsten; it also lost by ignition 7·86 per cent. According to Sjögren, the catapleite contains besides silica, 30 per cent. of zirconia, and 9 per cent. of water. According to the analyses by Berlin and v. Borck, eudnophite is an amorphous variety of analcime.*

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[*] Zeitschr. d. deutschen geol. Gesellschaft, i, 372.

[†] Naumann, op. cit. p. 577.

[‡] Scheerer.—n. Jahrb. f. Mineral. etc. 1843, p. 641.

[§] n. Jahrb. 1849, p. 770.

It is very interesting to find, as in this case, hydrated minerals imbedded in the mass of syenite, and not occurring in drusy cavities; it must be admitted, at least, that these minerals were produced in the wet way.

Syenite-porphyry contains imbedded in a matrix, crystals of felspar, oligoclase, magnesian-mica and hornblende. The accessory constituents are garnet, nephelin, titanite, quartz very seldom, magnetic oxide of iron, micaceous oxide of iron, and iron pyrites. Syenite-porphyry is more recent than syenite, which is traversed by veins of it.† In the mineral collection of v. Leonhard I found a specimen of syenite-porphyry from Zinnwald and Altenberg, containing red felspar crystals an inch long, and partially covered with a crust of kaolin, and partly decomposed at the interior. Some of the smaller crystals were quite decomposed. There can be no doubt that quartz would occur in syenite-porphyry presenting such alteration.

The more the hornblende rocks contain of accessory constituents, the greater has been the extent to which alteration has taken place in them. The previously-mentioned connection between the hornblende and mica is very distinctly recognizable in such instances. In some kinds of true syenite the hornblende crystals are surrounded or intersected with green laminæ of mica, Frequently the hornblende is wholly or partially replaced by mica. and in this case quartz also occurs. In the Harz there are some rocks resembling greenstone, in which the hornblende is replaced by black mica; and in the Fichtelgebirge there are masses of gneiss, in which hornblende replaces mica, while there is almost a total deficiency of quartz.‡ All these facts indicate conversion of hornblende into mica; for the former, even when aluminous, contains more silica than mica, especially magnesian-mica. Naumann remarks that mica and quartz are associated together, more especially where the syenite passes into granite, as, for instance, in the neighbourhood of Meissen; and inversely it might be said, that where hornblende disappears, in consequence of conversion into mica and quartz, there syenite passes into granite. There are instances of granite containing tolerably equal amounts of mica and hornblende, but generally one of these constituents preponderates in proportion to the other. In the Thuringian forest an alteration in the structure of the granite is presented in connection with the occurrence of hornblende, the granular rock assumes at these places a fibrous and gneissoid character.*

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* Poggend. Annal. lxxix. 299, et seq.

† G. Rose, op. cit. p. 377.

‡ Hoffmann.—Poggend. Annal. xvi, 537 and 549.

According to the investigations of Delesse,† the syenite of the Vosges contains two kinds of felspar, one of which is orthoclase, being distinguished by containing equal quantities of soda and potash. The other felspar has the following composition:—

	V.	VI.
Silica	58·92	58·91
Alumina	25·05	24·59
Peroxide of iron	trace	0·99
Sesquioxide of manganese	trace	trace
Lime	5·64	4·01
Magnesia	0·41	0·39
Potash	2·06	2·54
Soda	7·20	7·59
Water	1·27	0·98
	100·55	100·00
Density	2·683	2·651

V. Milk-white felspar from Ballon de Sevrance.

VI. Coral-red felspar from Coravillers.

The views entertained by Delesse and G. Rose, with regard to these felspars, have already been referred to.‡

Another felspar, that occurs sometimes in a fine-grained very hard rock at summit of the Hamelika, near Marienbad, and in the compact hornblende gneiss between the Kreutz and Ferdinand springs, is (according to Kersten's analysis) oligoclase, with equal amounts of potash and soda.§

The mineral, occurring in the dioritic pophyry, called andesite by v. Humboldt, and so frequently met with in the Cordilleras, was analysed by Abich,‖ and called by him andesine. It corresponds in composition very closely with calcareous oligoclase. Its density is 2·7328, nearly the same as that of calcareous oligoclase, and of that analysed by Forchhammer. Consequently, the presence of calcareous oligoclase in hornblende rocks cannot be doubted, and it is very probable that the rock in which the above calcareous oligoclase occurs is a hornblende rock.

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* Credner.—n. Jahrb. 1843, pp. 266, 267.

† Ext. des Mém. de la Soc. d'Emulation du Doubs.

‡ English edition, ii, 200.

§ n. Jahrb. f. Mineral. etc. 1845, p. 653.

‖ English edition, ii, 201, No. XXX.

The andesite of Popayan contains, according to Abich, together with calcareous oligoclase, hornblende and quartz, traces of epidote, and finely disseminated iron pyrites.

The two felspars, from the syenite analysed by Delesse, give, when the quantity of oxygen in the alkalies is taken as unity as above:—

	Oxygen in the Alumina.		Oxygen in the Silica.
Oligoclase from Sevrance	5·34	...	13·97
„ „ Coravillers	4·97	...	12·90

The oxygen of the alumina in the former felspar is certainly in larger amount than in any other of the above-mentioned specimens of oligoclase; but the other oxygen proportions correspond with them. There can be no doubt that several of the specimens of oligoclase referred to were, to a certain degree, altered. Therefore, in the analysis of syenite, in which the oligoclase is somewhat altered, the above calculated values for alumina and silica, according to the analyses of Delesse, may be modified. There would be obtained in this way:—

1. Alumina = $(0·16982\,k + 0·25659\,n)\ 11·42$
Silica = $(0·16982\,k + 0·25659\,n)\ 26·91$
2. Alumina = $(0·16982\,k + 0·25659\,n)\ 10·63$
Silica = $(0·16982\,k + 0·25659\,n)\ 24·84$

The hornblende crystals in the syenite of Sevrance consist of—

Silica	47·40
Alumina	7·35
Protoxide of iron	15·40
„ magnesia	trace
Lime	10·84
Magnesia	15·27
Potash, with some soda	2·95
Loss by ignition	1·00
	100·20

The loss by ignition varies in different specimens between a few thousandths and 1·49 per cent., and is probably due to water and hydrofluoric acid in the mica, which is intimately mixed with the hornblende. Delesse considers the large amount of alkalies to be essential constituents of it.

The amount of quartz is quite as large as in some kinds of granite; besides, titanite, magnetic oxide of iron and iron pyrites are associated with the hornblende. It is very abundantly traversed by blackish-green mica, which becomes more apparent after calcination, from the brown colour it assumes. Epidote occurs in this rock, in or near veins and cavities where it is surrounded by quartz. In rare instances the veins are filled with calc-spar. There are also a few very thin veins sometimes filled with a little epidote and perfectly pure orthoclase, but more generally with quartz and specular oxide of iron.

Delesse estimated by an ingenious contrivance the relative volume of the three principal constituents of syenite, and found for orthoclase at least one-half, for oligoclase one-fourth, and for hornblende and quartz also a fourth. These proportions are, however, subject to great variation, and sometimes there is much quartz, especially in syenite containing white oligoclase.

The larger amount of quartz in some syenite shows what has become of the silica that is deficient in white oligoclase that has undergone alteration.

A great number of varieties of syenite were examined by Delesse with the object of determining the sequence of the principal minerals independent of any theory. He considers that the orthoclase was produced first, and almost simultaneously with it the hornblende, while the oligoclase was produced subsequently; for very sharply-defined crystals of hornblende are often entirely surrounded by oligoclase. The quartz occupies the interstices between these minerals, and bears sharp impressions of their edges and corners. It is intimately associated with the crystals of oligoclase and sometimes traverses them. Sometimes hornblende, oligoclase, and even quartz, are imbedded in the orthoclase crystals;* but then the crystals are very small in proportion to the orthoclase, and frequently very large orthoclase crystals occur quite surrounded by hornblende, and especially by oligoclase. In the Ural, however, large crystals of black hornblende are imbedded in the felspar.†

Delesse remarks, that the sequence in the production of the mineral constituents of syenite does not correspond with their relative fusibility.

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* This is also the case with the syenite of the Thuringian forest. Credner.—n. Jahrb. 1848, p. 267.

† Kupffer.—Poggend. Annal. xvi, 274.

Where syenite does not contain any quartz, and consists merely of one-half orthoclase, one-fourth oligoclase, and one-fourth hornblende, the amount of silica in the rock would be 58 per cent. In those kinds that are free from quartz, the amount of silica cannot exceed 64 per cent., for that is the amount in orthoclase which contains a greater proportion than any other constituent of syenite. However, direct estimations of the silica in syenite have given larger amounts—

		Silica.
Syenite with red oligoclase	—Coravillers	65 per cent.
„ white „	Servance and Giromagny	70 „

Consequently, these varieties contain quartz.

Calculating the composition of syenite free from quartz, according to the above volume proportions, we obtain the following proportions by weight:—

Orthoclase	46·87
Oligoclase	24·52
Hornblende	28·61
	100·00

Calculating the composition of syenite containing 70 per cent. of silica, according to these proportions by weight, we obtain—

		Silica.
Orthoclase	33·58	21·58
Oligoclase	17·57	10·35
Hornblende	20·50	9·72
Quartz	28·35	28·35
	100·00	70·00

Calculating from these results the composition of syenite containing 70 per cent. of silica, and 65 per cent. according to the analyses of these constituent minerals by Delesse, we obtain the following amounts of the several constituents:—

Silica	70·00	65·00
Alumina	12·38	14·58
Peroxide of iron	0·17	0·20
Protoxide of iron	1·51	1·78
Lime	3·45	4·06
Magnesia....	3·46	4·08
Potash	3·13	3·69
Soda	3·44	4·05
Water	0·56	0·66
	98·10	98·10

These results serve for comparison with the analyses of hornblende rocks that are so fine grained that the constituent minerals cannot be separated and determined mineralogically. When the composition of such rocks, as a whole, approximates to the above, it may always be inferred that they are syenite. When the amount of silica is less than 64 per cent. they are free from quartz, provided the amount of alumina does not much exceed that given above; but if the amount of this earth, and also that of lime, are much greater, the presence of a more calcareous felspar may be inferred, and then quartz may be present also, because such a felspar would contain a smaller amount of silica than orthoclase or oligoclase.

Only two analyses of syenite have been published:—

	I.	II.
Silica	61·72	66·39
Alumina	13·57	13·79
Peroxide of iron	7·16	..
Protoxide of iron	..	3·61
„ of manganese	0·33	..
Lime	5·88	2·03
Magnesia	3·33	13·15 by deficiency
Potash	3·37	
Soda	3·12	
Water	0·95	1·03
		100·00

Analysed by

I. Syenite of Blansko, in Moravia Streng.[*]

A very intimate mixture of felspar, oligoclase, quartz, magnesian-mica, and hornblende. At some places there are small crystals of brown garnet.

II. Zircon-syenite of Maridal, in Norway Wiesnæs.[†]

From the analysis I, it is not possible to calculate the maximum amounts of the two felspars, because the amounts of lime to be assigned to the felspar and to the hornblende are not known. Nor can the magnesia be divided between the hornblende and the mica. Consequently, when the constituent minerals of syenite are so intimately blended that they cannot be separated, it is impossible to determine from the analyses of the rock, as a whole, what are the relative proportions of its constituent minerals. The amount of soda in I shows that the amount of oligoclase in this syenite must be considerable.

[*] Op. cit. p. 135.

[†] Jahrb. 1851, p. 839.

C.—PORPHYRY.

At Chagey, Haute Saone, a dark green rock occurs that has sometimes been regarded as augitic porphyry. It generally contains striped crystals of felspar that are generally greenish, and sometimes as dark as the matrix, rendering the porphyritic structure obscure. By the action of the atmosphere these crystals become at first brick red, and are then converted into kaolin. According to the analyses by Delesse* the felspar consists of—

Silica	59·95
Alumina	24 13
Peroxide of iron	1·05
Protoxide of manganese	trace
Lime	5·65
Magnesia	0·74
Potash	0·81
Soda	5 39
Water	2·28
	100·00
Density	2·736

The reasons for regarding this felspar as oligoclase have been given previously.†

The colour of this rock appears to be due to the presence of hornblende finely disseminated through the mass. It also contains some imperfectly crystalline blackish-green granules, which appear to be augite. The action of this rock upon the magnet shows the presence of a sensible amount of magnetic oxide of iron. Besides these minerals the rock contains carbonate of lime, iron pyrites, quartz, ferruginous chlorite, and epidote.

The analysis of the dark green matrix, which must contain the smallest proportion of felspar, gave—

Silica	61·71	
Alumina Peroxide of iron }	25·44	
Protoxide of manganese....	trace	
Lime	4·79	
Magnesia	2·98	
Potash Soda }	2·74	estimated from deficiency
Water	2·34	
	100·00	

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* Op. cit. p. 17.

† English edition, ii, 200.

These analyses of the felspar and the dark green matrix of this rock give the two opposite extremes of its composition, and a comparison of the two shows that the differences are but slight.

Since the amount of silica in the matrix is rather more than that in the felspar, the rock would appear to contain quartz; for the hornblende and other minerals it contains would reduce the amount of silica below that in the felspar. The presence of a larger amount of magnesia in the matrix than in the felspar is due to the admixture of hornblende. The density of the rock being little above that of felspar shows, however, that the amount of hornblende cannot be large. But this does not agree with the small amount of alkalies in the matrix, so that either the felspar in the matrix is much more decomposed than the crystals, or the alkalies have been estimated too low in the matrix.

This rock passes into an amygdaloid. The following estimations of the loss by ignition of several specimens show very distinctly the connection between this change and the hydration of the mass:—

	Loss by ignition.
1. Breccia porphyry	1·73
2. Dark green porphyry	2·79
3. Blackish-green porphyry	3·41
4. Green amygdaloid porphyry, passing into transition slate	5·32
5. Another specimen of the same	6·17

At one part the rock gradually passes into serpentine, with which it alternates in several places.

This rock may be regarded as a transition from true syenite into diorite. It differs from the former in not containing orthoclase, and from the latter in not containing anorthite, but a felspar more resembling oligoclase.

D.—HORNBLENDE SLATE.

The following specimens of hornblende rocks were analysed by myself, in order to ascertain how far the chemical examination would aid and confirm the mineralogical examination. All these rocks were so fine grained that the mineral constituents could not be separated mechanically. They were decomposed by carbonate of potash and by hydrofluoric acid, and great attention was paid to the estimation of the combined water which is indicative of the degree of alteration the rock has undergone. The density was also determined, as being of especial importance in the case of hornblende rocks, because the constituent minerals have a high density.

Hornblende Rocks without Quartz.

	I.	II.	III.	IV.
Silica	48·65	48·62	50·15	49·42
Alumina	16·42	20·19	13·30	18·12
Protoxide of iron	4·69	..	..	9·60
Peroxide of iron	18·62	12·15	27·54	5·41
Sesquioxide of manganese	0·48	trace	0·30	..
Lime	7·16	11·93	0·59	8·65
Magnesia	2·32	1·90	2·65	3·16
Potash	0·56	1·27	0·89	1·27
Soda	0·89	2·31	1·70	2·57
Loss by ignition	0·21	0·62	0·26	1·80
	100·00	98·99	97·38	100·00

I. Hornblende-slate from Miltitz, in Saxony.

The presence of felspar in this rock was not recognizable. Small crystals of hornblende were situated parallel to the stratification, and also crossing each other in all directions. There appeared to be also a green matrix, probably chlorite. The mass does not effervesce with acid, hot or cold. At the joints there is an ochre-brown substance that does not effervesce with acid. At 212° F. the mass lost but little water. Its density was 3·008 at 73° F.

II. Hornblende-slate from Hartmannsgrün, near Gieshubel, Bohemia.

The acicular crystals of hornblende were larger than in the former rock. It did not give off any water at 212° F., and did not effervesce with acid. Its density was 3·035 at 70° F.

III. Hornblende-slate from Kalvola, in Finland.

This rock contains large red garnets imbedded in it. Besides hornblende, it contains small laminæ of mica. It did not give off any water at 212° F., or effervesce with acid. Its density was 3·198.

The small amount of water in these rocks shows that they were but little altered.

IV. Hornblende rock from Weidenthal, at the foot of the Melibokus.*

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* English edition, ii, 353.

This rock contains, besides hornblende, a white mineral with a marked fatty lustre, which G. Rose describes as not being cleavable, but having a splintery fracture, and being scratched by a knife; so that it is not felspar. There is no appearance of quartz. It has already been remarked that this rock was coated with carbonate of lime at the joints, which may originate from an adjoining marl; but when the coating was removed, the powdered rock effervesced copiously with acid, 0·747 per cent. carbonate of lime being dissolved, so that it is probably a product of the decomposition of silicate of lime in the felspar. It was found very difficult to dry this rock at 212° F., and it still contained some water. All these circumstances show that alteration was far advanced, and hence it is probable that the white mineral was altered felspar.[*] Its density was 2·947 at 66° F.

Although the quantitative proportions of the bases on these specimens vary considerably, the amount of silica is tolerably uniform in all. A similar correspondence is presented by the amounts of silica in the felspar and hornblende from the diorite analysed by Delesse.

In Nos. I, II, and IV, as in that diorite,[†] the amount of lime is much greater than that of magnesia. If the amounts of both earths in the hornblende of these rocks were equal, the quantities of lime belonging to the felspar would be in I 4·84, in II 10·03, and in IV 5·49 per cent. But since the amount of magnesia in hornblende is generally greater than that of lime,[‡] the quantities of lime belonging to these felspars may be larger. Therefore it cannot be doubted that the felspar in these rocks is similar to that in the globular diorite, namely, anorthite, or a variety of that species, and consequently that the formulæ above given are not applicable to these rocks.

In No. III the amount of lime is very small, and that of magnesia larger, so that it cannot contain a calcareous felspar like the other rocks. Since also the amount of alkalies is small, and the density of the rock very high, it cannot contain much felspar.

Moreover, the large amount of iron, and the small amount of alumina in these four rocks show that the hornblende is the preponderating constituent, which agrees with their external appearance and high density. Consequently, these rocks differ widely from the globular diorite, in which felspar preponderates. It is probable that quartz does not occur in any hornblende rock that does not contain more than from 48 to 50 per cent. silica.

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[*] See ante, p. 275.

[†] See ante, p. 274.

[‡] English edition, ii.

The hornblende of these rocks, and especially that of No. III, are of that kind containing the largest amount of iron with the least lime and magnesia.

Quartzose Hornblende Rocks.

	V.	VI.	VII.	VIII.
Silica	58·90	61·09	60·97	61·04
Alumina	20·73	14·48	16·44	16·66
Protoxide of iron	9·83	8·95	10·58	9·09
Oxide of manganese	..	0·93	0·08	..
Lime	5·32	5·01	5·14	1·18
Magnesia	2·01	0·85	1·80	1·84
Potash	1·80	1·36	0·80	2·17
Soda..	2·09	1·81	3·41	2·85
Loss by ignition	0·99	1·82	1·03	3·55
	101·67	96·30	100·25	98·38

V. Hornblende rock from the Schonberg valley.*

This rock contains small blackish-green prismatic crystals of hornblende, small brownish-black laminæ of mica, and a white, fine-grained mineral that is cleavable, and is not streaked at the cleavage surfaces, so that it is probably orthoclase. This rock may contain oligoclase also, because the cleavage of the white mineral is not always recognizable. It does not effervesce with acids. The density is 2·820 at 77° F.

VI. A similar rock in a decomposed state.

VII. Very fine-grained rock adjoining coarse-grained diorite, from a quarry in the Weidenthal, on the road from Zwingenburg to the Melibokus.†

It contains here and there small yellow particles, probably copper pyrites, since ammonia gives a blue colour with the solution. G. Rose does not consider this to be hornblende slate, because no hornblende is recognizable. It is similar to the green slates that occur between Kupferberg and Schönau, in Silesia, but the similarity of its composition with those of the above hornblende rocks shows that it is related to them. The powder effervesced with acids, and its density was 2·814 at 71° F.

VIII. A rock resembling felspar porphyry, between Rammelsbuch and Alten-Glan, in Rhenish Bavaria.

G. Rose describes this as syenite-porphyry. Very minute cavities, surrounded with a flesh-coloured mineral, contain a greenish mass resembling chlorite. A piece of the rock boiled with water, gave off numerous bubbles of gas, showing that it was very porous. It did not effervesce with acid, though 0·08 per cent. was dissolved out. The density of the rock was 2·687 at 66° F.

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* See ante, p. 265.

† English edition, ii, 353

In Nos. V, VI, and VII, the amount of lime again exceeds that of magnesia, so that these rocks do not contain a calcareous felspar. If the amounts of these earths in the hornblende of these rocks were equal, the lime belonging to the felspar would be in V 3·31, in VI 4·16, and in VII 3·34 per cent. According to the proportion of this constituent of the rock, these quantities would amount to such a percentage of lime as is unknown in any oligoclase but the calcareous variety.*

It is not probable that No. VI has originated by the alteration of No. V, at least it could not be shown how the amounts of alumina and magnesia were reduced. The powder of No. V was gray, that of No. VI yellowish, so that the principal alteration may have consisted in peroxidation of iron.

No. VII is evidently much decomposed, but the similarity in composition to the other rocks shows that it is of the same class. Since it differs from these chiefly in the small amount of lime, it is very probable that the alteration consisted in abstraction of lime.

Since the amount of iron in these hornblende rocks is less than in the former ones, they probably contain a smaller proportion of hornblende.

The amount of silica in calcareous oligoclase falls between 59 and 61·2 per cent., corresponding exactly with that in the rocks No. V to VIII. Since, however, the amount of silica in hornblende is considerably less than this, the amount of silica in these hornblende rocks would be less in proportion to the amount of hornblende they contained, unless they also contained free silica. The laminæ of mica in No. V are insufficient to influence the composition of the rock sensibly. Consequently there can be no doubt that the rocks Nos. V to VIII contain quartz, though it is not recognizable. No. V gives sparks when struck with steel.

In a melaphyr rock near Niederkirchen, in Rhenish Bavaria, there is a red felspathic mass associated with hornblende, and small particles of specular iron. In some parts it also contains quartz granules. This rock contains small fragments of datolite. Its geognostic features are very remarkable, forming veins in the

* See ante, p. 278.

weathered melaphyr, contorted in all directions. Similar veins occur in the melaphyr on the Eisenknopfe, near Eschweiler, and at the Heidenburg near Kreimbach. This rock resembles the above mentioned syenite-porphyry.

Although the particles of felspar are large, they are so traversed with hornblende that separation is very difficult. There appear to be two kinds of felspar, one pink, the other white, but they could not be separated. The hornblende has at some parts a green chloritic coating, which also lines some of the cavities. This rock lost by ignition 0·81 per cent., so that it was to some extent altered. The felspathic portion, still containing some admixture of hornblende, was decomposed by hydrofluoric acid, and gave on analysis—

Silica	65·82
Alumina	17·45
Peroxide of iron	2·98
Lime	1·13
Magnesia	1·56
Potash	1·83
Soda	9·23
	100·00

Hence it is very probable that it was a mixture of orthoclase and oligoclase, in which part of the alumina is replaced by peroxide of iron, and consequently the rock would be a syenite almost free from quartz.

The occurrence of this syenite in such very small interlacing veins in melaphyr is quite inconsistent with the opinion that it is of igneous origin, however the melaphyr may have been produced.

The density of this mass is 2·754 at 66° F., so that the felspathic matrix must preponderate largely over the hornblende.

In the vicinity of Halle on the Saale, eastwards of Löbejün, and nearly at the boundary of the old porphyry, there is a small isolated peak called the Scheidsberg. It is prolonged towards the west as a narrow strip, and reaches almost as far as the midst of the Löbejün coal measures. The mass of this mountain has a perfect porphyritic structure, which gradually disappears in proportion to the distance from the mountain, and the rock ultimately passes into a compact greenstone. The several varieties of this rock were analysed by Hochmuth.* He speaks of one constituent as being augite, but Rammelsberg† is of opinion that it is more probably hornblende. This is the more probable, from the fact that augite appears to be always associated with labradorite, which is not present in this rock.

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* Bergwerksfreund, xi, 441.

† Handwörterb. 4th suppt. p. 181.

	I.	II A.	II B.	III.
Silica	66·19	64·25	61·50	59·87
Alumina	13·43	12·64	13·78	11·21
Peroxide of iron	6·46	8·63	11·89	14·88
Lime	0·46	2·50	1·20	5·87
Magnesia	2·36	1·14	1·58	
Potash	5·08	4·33	7·39	5·09
Soda	2·56	2·60		
Loss by ignition	2·57	1·15	2·66	2·54
	99·11	97·24	100·00	99·46

I. Porphyry of the Scheidsberg.

This rock is a dirty yellow colour, compact and hard. It contains two kinds of felspar crystals, orthoclase and opaque white felspar, more likely to be albite than oligoclase. It also contains small particles of greenish-black augite, or hornblende and quartz, though very seldom. Its density was 2·6317. When exposed to the atmosphere it crumbles and assumes an ochrey colour. The greenish-black mineral then becomes covered with hydrated peroxide of iron.

II. Porphyry of the Martinschacht.

The matrix of this rock is dark brownish red, passing into brownish-yellow, green and blue. The felspar crystals are smaller and less distinct. A few black spots have the appearance of augite or hornblende. In the place of these there are generally cavities filled with small green needles, probably epidote. Its density was 2·6486. A is the analysis of the ordinary rock; B of a pale green variety, in which no felspar is imbedded. Its density was 2·683.

III. Greenstone, occupying a hollow in the coal measures at the extremity of the porphyry.

Dark leek green, compact and very hard. By the aid of a magnifying glass, it was found to contain felspar, and rarely quartz. The nature of the green mineral could not be determined. This rock is connected with the porphyry by the rock No. II B.

Hochmuth calculates from these analyses the proportions of potash-felspar, soda-felspar, augite and quartz.

The calculation of the amount of felspar must be very uncertain, on account of the varying amount of alkalies. The small amounts of lime and magnesia do not indicate the presence of a very calcareous felspar. But since in No I the amount of magnesia is greater than that of lime, it is probable that the rock contains hornblende, and not augite.

Calculating, by means of the formulæ for orthoclase and albite, the amount of felspar in No. I, there remain 27·84 per cent. silica, and 3·2 per cent. alumina. The oxygen of both amounts to more than 2·5 times that of the protoxide of iron, the lime, and magnesia, so that, assuming the presence of hornblende containing alumina, there is free silica present to the amount of at least 18·84 per cent., and at the utmost 20·74 per cent.

Calculating in like manner the amount of felspar in II, there remains 28·93 per cent. silica, and 3·22 per cent. alumina. The oxygen of both amounts to more than 2·5 times as much as that of the above-named bases, and therefore, assuming the presence of aluminous hornblende, there is free silica in the rock to the extent of from 17·04 to 19·41 per cent.

In Nos. I and II there are obtained, after deducting the maximum or minimum of silica, residues, whose compositions give positive values for x which are less than the oxygen of the alumina, and may therefore be regarded as representing hornblende. The residue of No. II certainly contains more lime than magnesia, and therefore does not correspond with the composition of hornblende. However, the considerable loss by ignition shows that these rocks are to some extent altered, and that they cannot be any longer in their original proportion. Moreover, it is probable that a portion of lime may belong to the felspathic constituent.

Calculating the amount of felspar by means of the formulæ for oligoclase, there is 14·11 per cent. of alumina obtained for No I, and 12·99 per cent. for No. II, in both instances exceeding the amount in the rocks. In any case there can only be a very small amount of oligoclase present; for since hornblende rocks always appear to contain aluminous hornblende, a portion of the alumina may belong to hornblende. Since in the calcareous felspars the amount of alumina augments together with the lime, and reaches the maximum in anorthite, the presence of only a small amount of these two earths admits of its being safely inferred that such felspar is not present at all, or to any sensible amount.

The constituents of the rocks Nos. I and II*a*, calculated by these formulæ, are:—

	I.		II A.	
	Minimum of quartz.	Maximum of quartz.	Minimum of quartz.	Maximum of quartz.
Felspar	51·67	51·67	56·22	56·22
Quartz	17·04	19·41	18·84	20·74
Hornblende	27·38	25·01	21·48	19·58
	96·09	96·09	96·54	96·54

The term felspar here refers to orthoclase, albite, or oligoclase. In the case of Nos. II*b* and III the nature of the felspar cannot be determined with certainty, because the alkalies were not estimated directly. But these rocks are very closely related to the others in composition.

The amount of protoxide of iron increases almost in the same proportion as the amount of silica diminishes. But it cannot be determined with probability whether one has originated from the other or not.

The black greenstone, No. IV, presents some resemblance to No. I; and a compact greenstone, No. V, resembles No. III. Both rocks are from the Hodritsch valley, near Schemnitz, and were analysed by Beudant.*

	IV.	V.
Silica	63·2	60·0
Alumina	14·2	12·3
Peroxide of iron	5·8	12·3
Protoxide of manganese	..	3·1
Lime	2·5	1·4
Magnesia	2·0	..
Potash	1·2	9·6
Soda	1·2	1·1
Water	0·3	0·2
	90·4	100·0

The unusually large amount of potash in No. V is remarkable. In the analysis No. IV there is probably a typographical error. Rammelsberg† conjectures that the amount of potash should be 11·2 per cent. The total absence of magnesia, and the presence of so large an amount of manganese in No. V, is also remarkable.

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* Ann. des Mines, 2, v, 300.

† Handwörterb. p. 196.

So far as investigation has yet been carried, there are five species of felspar that occur in hornblende rocks, namely, orthoclase, albite, oligoclase, calcareous oligoclase, and anorthite. If the rocks containing orthoclase, or orthoclase and oligoclase, are called syenite, then all the others which do not contain orthoclase, but one of the other species of felspar, must be called diorite. Then there would be several varieties of diorite, according as they contain one or other species of felspar, and when two of these are associated the rock would be named according to the one which preponderated.

The globular diorite of Corsica, the hornblende slates of Siebenlehn, Miltitz, Hartmannsgrün, and the Weidenthal, appear to be really anorthite-diorite. The diorite of Pont-Jean may be oligoclase-diorite, and the hornblende rock of Baumgarten, of Pisoje, and of Russgarden, may be calcareous oligoclase-diorite. It is certain that the hornblende slate of Kalvola is neither anorthite-diorite nor calcareous oligoclase-diorite, but it is uncertain what it is. The quartzose rocks of the Schonberg valley, and of the Weidenthal, appear to be calcareous oligoclase-diorite, probably also the rock at Rammelsbuch, though the advanced decomposition of the latter renders this uncertain.

The syenite of the Vosges appears to be very definitely characterized. The rock at the Sattel may likewise be a syenite. The mineralogical examination of the rocks near Halle is too superficial to afford any clue to their mineral constituents; moreover, they are considerably altered. The result of the analyses I and II are, however, not opposed to the opinion that these rocks are quartzose syenite, containing but very little hornblende.

The density of the different species of felspar occurring in hornblende rocks are—

Orthoclase	2·50	...	2·60
Albite	2·61	...	2·64
Oligoclase, calcareous Oligoclase and anorthite	2·64	...	2·76
Hornblende	2·93	...	3·40

Therefore, the density of a hornblende rock cannot be less than 2·5 or more than 3·4, provided it does not contain any other constituents than felspar and hornblende. The density is of course greater in proportion to the amount of hornblende, or for like amounts of this constituent, according as the rock contains anorthite, calcareous oligoclase, or oligoclase. The density of quartz varies between the same limits as that of felspar, so that for like amounts of hornblende the density of hornblende cannot be much affected by the presence of quartz.

Among the above-mentioned hornblende rocks the globular diorite of Corsica and the rock from the Sattel approximate to the minimum density; consequently they contain much less hornblende than felspar. The density of the hornblende rocks without quartz falls between 2·947 and 3·198, so that they contain nearly equal parts of hornblende and felspar. The density of the quartzose rocks falls between 2·687 and 2·820, so that they contain less hornblende than those without quartz. The rocks from the vicinity of Halle have the lowest density—2·6317—2·683, consequently they contain the smallest amount of hornblende.

Intermediate between the rocks containing hornblende and those containing augite, recognizable mineralogically, are the great diversity of greenstones, greenstone slate, aphanite, diabase, etc. When hornblende or augite are no longer recognizable, except by the colour they communicate to rocks, it may happen that hornblendic and augitic rocks of like chemical and mineralogical composition may present very different colours, according to the degree of oxidation of the iron which determines the colour of both hornblende and augite. It has already* been pointed out that the blue colour of melaphyr passes into bright-green, yellowish-green, and ochre-green, according to the stage of decomposition; and this is undoubtedly the case also with hornblende rocks.

Naumann† remarks, that the great majority of greenstones are characterized by containing augite, and comparatively few by containing hornblende. With this opinion I quite agree. The slender aid that mere chemical analysis affords in determining whether a rock contains hornblende or augite has been pointed out already, and especially by the doubt as to whether the rocks analysed by Delesse‡ are to be regarded as melaphyr or hornblende rocks. Since hornblende contains fluorine, while augite does not, this difference might, perhaps, serve for distinction. In any case it is very desirable that an extended investigation of such rocks should be undertaken for the purpose of ascertaining what differences exist between augitic and hornblende rocks. It will subsequently be shown that the hornblende rocks containing metallic ores, in the Erzgebirge always contain fluor-spar, which is most probably a product of the decomposition of hornblende. This conjecture gains in probability, when it is remembered that among the localities in which fluor-spar has been found, its occurrence in vesicular cavities in amygdaloid rocks at Papastour, on the Scotch coast, is mentioned only once, and that it is uncertain whether this amygdaloid is really an augitic rock.

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* See ante, p. 206. † Lehrb. der Geogn. i, 592. ‡ See ante, p. 221.

It may be supposed that the products of decomposition transferred from the mass of rock into the cavities would indicate whether the rock were augitic or hornblendic; for, although hornblende undergoes almost the same kinds of alteration as augite, it may be expected that hornblende rocks would yield other products than augitic rocks since the two kinds of rocks generally contain quite different species of felspar, which yield different products in their conversion into zeolites.

It is remarkable that prehnite occurs by far most frequently in hornblende rocks, especially in cavities and fissures in diorite. This circumstance might induce one to infer, from the occurrence of prehnite in a greenstone where the presence of hornblende could not be recognized, that it contained hornblende. But since it is, in most instances, uncertain whether rocks described as diorite are really diorite, the statement as to the occurrence of prehnite in diorite still less admits of the inference that the rocks referred to are really diorite. In addition to this, prehnite occurs pseudomorphous after analcime, leonhardite, and natrolite, zeolites that generally occur in augitic rocks, such as dolerite, basalt, &c. This shows the possibility that prehnite may originate indirectly from augitic rocks, and is opposed to the conjecture that it is only a product of the decomposition of hornblende rocks. At the same time it is remarkable that the pseudomorphous prehnite after analcime* occurs, among other places, at the Sattel, near Niederkerchen, where the above-mentioned red felspathic rock containing hornblende occurs.

As to the mode in which the prehnite in cavities and fissures has been produced, only conjectures can be formed. But it is scarcely possible to imagine any other mode than the deposition from water containing silicates of lime and alumina; and, if that is the case, its production from hornblendic and augitic rocks would be equally intelligible.

The numerous veins of prehnite in the greenstone near Dillenburg is very remarkable. That occurring in a thick vein near Niederschelt effervesces at many parts with acid; but whether the carbonate of lime is a product of the decomposition of prehnite, or a simultaneous deposit, I will not venture to decide.

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* English edition, ii, 142.

The occurrence of prehnite in this greenstone does not justify the inference that it is diorite. F. Sandberger* speaks of perfectly crystalline diorite, consisting of albite and hornblende. But Grandjean states that, in the Nassau district, there are not any albitic diorites. In the vicinity of Dillenburg he showed me in a greenstone, labradorite crystals half-an-inch long, partly quite sound and partly more or less weathered. In this instance, therefore, the rock is not diorite; but generally these greenstones are so fine-grained that it is impossible to distinguish the felspathic from the augitic or hornblendic constituents. On the road from Burg to Neuhaus I found these rocks of such a dark-blueish black colour that they could not be distinguished from true melaphyr.

It appears to be quite in vain to attempt a classification of greenstones. They constitute a series, the extreme members of which are, on the one hand, augitic porphyry or melaphyr, with distinguishable augite and labradorite; and on the other, diorite or syenite, with distinguishable hornblende. Between these opposite extremes, there are innumerable intermediate varieties, with regard to which, it is quite uncertain whether they are to be classed with augitic or hornblendic rocks. It is also certain that the disposition to regard only the two classes of rock as being comprised among greenstones, indicates an exaggerated desire for classification. There can be no doubt that in many instances the green colour of these rocks is due to the presence of minerals that are products of the alteration of hornblende or of augite, and also of the felspars associated with these latter minerals. Prehnite, epidote, chlorite, and similar minerals, containing protosilicate of iron, which are met with in veins and cavities of greenstone more or less distinctly, would also occur in the mass of these rocks as products of alteration. Considering further that augite, in the matrix of melaphyr, may by elimination of lime, and with or without substitution of magnesia, be converted into hornblende, and perhaps also into diallage, bronzite, hypersthene, etc., and that this alteration may be more or less advanced, it will be evident that innumerable combinations of these products of decomposition may occur in greenstone. Consequently, it could not be wondered at if a bed of greenstone were found to consist at one end of melaphyr, at the other end, perhaps of anorthite-diorite, with innumerable intermediate transitions. Therefore, when the constituent minerals of greenstone cannot be determined mineralogically, it is most convenient to adhere to this general term.†

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* Urbersicht, etc., p. 64.

† Compare Naumann, op. cit. p. 592.

Delesse* analysed the felspar from the euphotide, which may be regarded as a variety of gabbro. This euphotide effervesced with acids, and contained carbonates of iron, lime, and magnesia, penetrating not only the felspathic matrix and the felspar crystals, but also the diallage crystals, and all circumstances showed that this rock is the seat of constant and diverse processes of alteration.

The composition of the saussurite † from the euphotide of Corsica approximates sometimes to that of labradorite, sometimes to that of the felspar called vosgite by Delesse, and sometimes even to that of anorthite. It presents unmistakable indications of transition from labradorite into anorthite, and it may result from this that in greenstone there is a gradual transition, not only of the augitic constituent into hornblende, but also of the labradorite into anorthite. If this is the case, it would not be possible to draw any distinction between augitic and hornblende rocks, either by means of their felspathic or other constituents. Since the latter rocks contain besides anorthite, oligoclase, albite and orthoclase, it will be seen that it is precisely those species of felspar that are of most frequent occurrence which enter into the composition of augitic and hornblendic rocks, especially the latter.

Since saussurite has a density varying from 3·2 to 3·4, or nearly the same as augite, the presence of this felspar may be inferred in a greenstone that has such a high density, especially when the felspathic constituent preponderates. The presence of saussurite in augitic or hornblendic rocks is the more probable since smaragdite, which, together with saussurite, constitute euphotide, is a mixture of augite and hornblende, or else the product of a partial conversion of the one into the other.

The mineral called diallage, from the euphotide of Fiumalto has, according to Boulanger's analysis, a composition very different from that of diallage. It contains only 40·8 per cent. of silica. Although it is not easy to understand how this mineral can be diallage, augite, or hornblende in an altered condition, scarcely any other view of the case can be taken. The large amount of 5·2 per cent. of water in this mineral certainly indicates far advanced decomposition. If, as may be conjectured, greenstones contain similar minerals produced by decomposition, and analagous to zeolites, the difficulty of determining, from the chemical analyses of rocks containing such minerals, what their constituents are, would be very much increased.

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* Recherches sur l'Euphotide. Bulletin de la Soc. Géol. de France, 2, vi, 547. See also English edition, ii, 217.

† English edition, ii, 218.

The fact that gabbro, euphotide, and even hyperite cannot be distinguished from greenstone when they are fine grained, sufficiently justifies the classification of these rocks with greenstone.

Alteration and decomposition of hornblende rocks.—The conversion of hornblende into chlorite, mica, and serpentine, indicates the possibility of the conversion of hornblende rocks into chlorite-slate, mica-slate, and serpentine. The following facts show that such changes really take place.

To the west of Grünau, in the Erzgebirge, a mass very similar to hornblende-slate occurs on a peak consisting of greenstone or greenstone-slate that is partly compact, and partly even vesicular. This hornblende-slate extends towards the north-west, and gradually passes into hornblendic chlorite-slate, and then into mica-slate in such a manner that the latter rock preponderates considerably on both declivities of the Schönau valley, and upon the heights between this and the Loh valley. On the contrary, the peaks at both sides of the Loh valley consist of hornblendic greenstone; however, this rock occurs but in a very subordinate proportion.

It might be supposed that in this instance there had been a series of alterations, and Naumann adds that these different rocks must be regarded as integral portions of one and the same rock—as simultaneous products, notwithstanding the great dissimilarity of these rocks, the undulating mica-slate, and the compact greenstone. This is shown by the most distinct transitions which may be traced in the rocks, so that the supposition becomes a certainty.

By a proper application of the facts of pseudomorphism, it is possible to determine what was the starting point of these alterations. There is no instance of the conversion of mica into chlorite or into hornblende, consequently the mica-slate cannot have been converted into chlorite-slate and compact greenstone, but the latter must have been converted into chloritic and mica-slate.

The green colour of the mica in this slate also indicates that it has been produced from hornblende, and the occurrence, in some parts of the rock, of grey mica in the place of green mica, can only have been due to the peroxidation of the iron in the green mica. If it were the potash in the felspathic matrix of the greenstone that gave rise to the conversion of the hornblende into mica, the amount of felspar would diminish in proportion as this alteration advanced and mica slate was produced, the quartz of this rock originating from the silica of the decomposed felspar, unless the greenstone itself contained free silica. Naumann states, however, that the mica-slate sometimes contains felspar, and then presents, in some places, a gneissoid appearance.

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* Naumann.—Erläuterungen, ii, 309.

The nature of the conversion of chlorite-slate into mica-slate is still obscure, for there is no pseudomorph indicating the conversion of chlorite into mica. But on chemical grounds, it is possible that this alteration may take place, because the essential difference between chlorite and mica consists in the latter containing alkalies. Mineralogically, chlorite cannot always be distinguished from mica. If the mica-slate still contains chlorite, it would not be necessary to suppose that the mica has been produced from chlorite. If layers of chlorite-slate are frequent in the mica-slate, the two minerals may have been produced simultaneously.

In the conversion of hornblende-slate into chloritic or mica-slate, lime must be eliminated. On the left declivity of the Schönau valley there are, in fact, a number of masses of limestone immediately above the mica-slate.* It is, however, uncertain whether they have originated from the decomposition of the greenstone. As their stratification varies very much, it cannot be inferred that they were deposited simultaneously with the greenstone and the mica-slate that has originated from it.

The fact that the greenstone at this place occurs on the heights, while the chlorite-slate, containing hornblende and mica-slate, occurs on the declivities, shows that the conditions of alteration prevailed more at the lower than at the higher points. It may, therefore, be conjectured, that the water flowing from the heights carried with it the substances requisite for producing the alteration.

In the districts of Breitenbrunn and Schwartzenberg, in the Erzgebirge, the mica-slate, in which the stratification and cleavage is tolerably parallel, is traversed at many places by a number of very different rocks, the chief mass of which partly resembles greenstone and partly limestone, and which are characterized by the abundance and diversity of the imbedded minerals and poor metallic ores. The very frequent association of metalliferous hornblende rocks with granular limestone or dolomite, which are not very distinct from each other, is especially remarkable.

In the Breitenbrunn range the beds are separated into an upper and lower section. The upper one, called the "Kamm," consists of a mixture of chlorite, hornblende, and actinolite. The lower one—the true ore stratum—consists chiefly of magnetic iron ore, pyrites, blende, tin ore, garnet, vesuvian, actinolite, chlorite, clay, and hornblende; more rarely containing quartz, calc-spar, brown-spar, fluor-spar, apatite, diopsite, sahlite, epidote, tourmaline, mica, talc, and picrolite.

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* Op. cit. p. 315.

In the Unverhofft Glück deposits there are also two sections. The upper and smaller one, being the ore stratum, is a hard greenstone, with actinolite, quartz, erlan, nacreous carbonate of lime, manganese-spar, brown-spar, blende, pyrites, and argentiferous galena; containing more rarely picrolite, epidote, helvin, allochroite, green mica, serpentine, fluor-spar, and peponite, as well as metallic silver in cavities, and at the upper part pyromorphite and carbonate of lead. The lower section consists of granular limestone and dolomite.

In the deposits at Schützhause the overlying bed, from half-a-fathom to two fathoms thick, consists of greenstone, with actinolite, garnet, quartz, prasem, nacreous carbonate of lime, calc-spar, fluor-spar, blende, magnetic iron ore, copper pyrites, galena, more rarely epidote, amethyst, helvin, and allochroite. The underlying bed, from one-third to three-quarters of a fathom thick, is generally granular limestone and dolomite, together with iron-spar, and the purest limestone is situated lowest.

The mines, "Zweiglers Fund" and "Neujahr," in the Wildenau deposits are very like the "Unverhofft Glück" mine. Noble serpentine, jasper-opal, actinolite, diopside, vesuvian, allochroite, garnet, eupholite, peponite, fibrous limestone, metaxite, picrolite, woollastonite, gypsum, fluor-spar, magnetic iron ore, copper pyrites, iron pyrites, blende, and galena, are generally blended with the greenstone. The granular limestone is very pure, and in "Zweiglers Fund" contains sharp-edged fragments of greenstone.

The above-mentioned greenstones are considered by Cotta to be diorite. At least in many places there is diorite, consisting of recognizable albite and hornblende, without any foreign admixtures.

Assuming that the two sections of the Breitenbrunn range originally consisted of diorite, and that in consequence of the permeation of water decomposition has progressed from above downwards, the soluble products being carried down by the water and deposited in the lower portions of the diorite, the lime of the decomposed hornblende and albite, a part of the magnesia from the former, and the greater part of the iron, would thus be carried down to the lower beds, where they occur as calc-spar, brown-spar, and magnetic iron ore. The residues of the hornblende and albite would consist chiefly of silica, magnesia, and alumina, which are found as quartz or prasem, and as chlorite. The presence of hornblende and actinolite in overlying beds shows that the alteration is not yet complete. The other minerals occurring in the underlying beds are partly products of infiltration from above, partly products of the reaction between the substances brought down from above by water, and the constituent minerals of the diorite constituting the underlying beds. The pyrites, blende, tin ore, fluor-spar, and apatite, are the products of infiltration; garnet, vesuvian, diopside, sahlite, epidote, tourmaline, mica, and picrolite, have originated in the latter mode. The presence of chlorite and quartz in the underlying beds shows also that the same processes of alteration have gone on there, though to a less extent, and the presence of hornblende shows that the alteration is not complete. The metalliferous minerals occurring only in the lower beds are probably not only derived from the upper beds, but also in part produced on the spot. This is the more probable from the fact that in the Raschau deposits the mass of the rock is compact and hard where there is but a small quantity of imbedded pyrites, while at the places where iron pyrites and arsenical pyrites preponderate, the rock is entirely altered, and resembles wacke.

The phenomena presented by the deposits at the "Unverhofft Glück" mine, lead to the conclusion that the eliminated lime and magnesia are deposited below the greenstone as carbonates. In proportion as the mass of the rock was diminished at the upper part, and space was afforded, new minerals were deposited in the lower parts; and if the whole quantity of the earth was deposited, the mass and volume would have been augmented by combination with carbonic acid. In this way, perhaps, a layer was produced in the same manner as the layer of carbonate of iron at Wehr.* The presence of carbonates and of quartz are sufficient evidence of decomposition having taken place in the upper beds. The absence of chlorite in the "Unverhofft Glück" deposits may be accounted for by the presence of dolomite in the underlying beds, and of brown-spar in the overlying beds; for when the magnesia occurs as carbonate, neither chlorite, nor any other silicate of magnesia could not have been produced. However, the more rare occurrence of serpentine and picrolite shows that a portion of the silicate of magnesia escaped decomposition by the carbonated water. The difference between the processes of decomposition at Breitenbrunn and at the "Unverhofft Glück" consisted, therefore, in the preponderance of the separation of magnesia as carbonate at the latter place.

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* English edition, i, 156

It must not be overlooked that the singular rock, which Breithaupt* calls erlan, constitutes, together with mica, a member of the oldest gneiss series, because it appears to afford an indication of what has become of the albite belonging to the diorite. At one place there were in this rock beds of a red felspar as fine grained as erlan. The distinctly-stratified mixture of erlan and mica occurs between Gross Pöhla and Erla as a bed of at least a hundred fathoms thick. Breithaupt regards erlan as a distinct mineral species, but Berzelius,† judging from the results of analysis, considers it to be merely a mechanical mixture. Since, however, it contains only 2·6 per cent. of soda, together with 14·4 per cent. of lime, 5·4 per cent. of magnesia, and 7·1 per cent. of peroxide of iron, other materials than albite must have contributed to its production. In the present instance, hornblende may have yielded the lime, magnesia, and peroxide of iron. The beds at Graul belonging to the Raschau deposit, which contain in the wacke or principal mass, resembling greenstone, besides hornblende-slate, actinolite, sahlite, kaolin, etc., show that the albite was sometimes merely converted into kaolin.

It is remarkable that in the "Weisser-Adler" mine, which is only a hundred paces from the "Unverhofft Glück, the relative position of the deposits of ore and stratified masses is entirely reversed. Limestone and dolomite are there at the top and the thickest beds, while greenstone and the ores are underneath. At one place, however, there are still vestiges of greenstone overlying the limestone, and hence it is probable that the greenstone mass from which these carbonates have originated has been almost entirely destroyed.

The view put forward with regard to the production of the above metalliferous deposits is also applicable to the deposits at Schutzhause and Wildenau. At the former place the decomposition by carbonated water is more advanced, for it has affected the protoxide of iron in the hornblende, as is shown by the presence of iron-spar in the underlying beds. This also agrees with the fact, that among the products of decomposition there are not any minerals containing silicate of magnesia. The Wildenau deposits, on the contrary, contain noble serpentine, which appears to have taken the whole of the eliminated magnesia, since the limestone is very pure.

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* Schweigg. Journ. xxxviii. 76.

† Jahresbericht, iv, 158.

The conversion of hornblende into steatite* or talc does not appear to have been frequent at these places. It is only at the "Sechs Bruder" bed in the Klobenstein deposits that steatite occurs together with serpentine, and at the "Gross Pöhla" bed that talc occurs together with noble serpentine.

The "Gross Pöhla" group of beds is very interesting, because the relative positions of the limestone and greenstone are better shown than elsewhere. The lowest bed consists of magnetic iron ore and actinolite. Then follows greenstone, and after that a bed containing ores, and mixed with limestone, in which there are brown-spar, nacreous carbonate of lime, talc, noble serpentine, epidote, helvin, amianth, fluor-spar, blende, argentiferous galena, and magnetic iron ore. This is followed by granular limestone, or perhaps dolomite, which is traversed by a narrow vein of a mass resembling wacke.

If the chemical possibility of several of the above-mentioned alterations of hornblende and albite were the only ground for the opinion that they actually take place, it might be open to objection; but there is also mineralogical evidence that this opinion is correct, furnished by the pseudomorphs after hornblende.

Chlorite and serpentine occur with the form of hornblende.† Both in the conversion of hornblende into chlorite, and in its conversion into serpentine, there must be elimination of lime. Therefore, when a rock contains, besides undecomposed hornblende, either chlorite or serpentine, together with carbonate of lime, there is nothing opposed to the opinion that these minerals are products of the decomposition of hornblende. Since jasper occurs with the form of hornblende,‡ it is possible that by a further decomposition this mineral may be produced. Jasper-opal occurs also in kaolin, so that it may likewise be a product of the decomposition of albite. The occurrence of fluor-spar among the products of decomposition is due to the presence of fluorine in hornblende.§ Lastly, since hornblende passes into an asbestiform condition, metaxite and peponite may probably be altered hornblende.

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* English edition, ii. 347.

† Ibid. ii, 346.

‡ Ibid. ii, 349.

§ See ante, p. 298.

At the above-named places diorite appears, as at the Turjin copper mines,* to be an ore-bearing rock, and at both places enormous masses of diorite must have been destroyed. Since at such remote places the origin of metallic ores from the same kind of rock is unquestionable, it will not be necessary to anticipate the remarks that will be made on the origin of ores generally, beyond pointing out that neither magnetic pyrites, iron pyrites, copper pyrites, arsenical pyrites, galena or blende exist in diorite any more than magnetic iron ore or iron-spar exist in hornblende. Since long-continued processes of decomposition must have gone on in this rock before the small proportion of metals that it contains could become so concentrated as to be worked, it may be understood that enormous masses of water must have permeated the rock, and that in this way the conditions for the production of metallic sulphurets may have been supplied. Gypsum occurs in the deposits at Wildenau and other places. It cannot be doubted that the water introduced organic substance to some extent. By the reaction of this organic substance with the sulphates, the metals, probably existing as oxides in the diorite, would be converted into sulphurets.

It has already been remarked that the greenstone and limestone, constituting the two members of the deposits in the Erzgebirge are mixed together between Grünsättel and Crandorf.

The silicate of lime in albite will, by complete decomposition, yield 6·6 per cent. of carbonate of lime, and that in hornblende will yield 25·3 per cent. Therefore the production of a mixture of diorite and carbonate of lime might be accounted for upon the assumption that the mass was originally diorite, and that a portion of it was decomposed by atmospheric carbonic acid. The only circumstance opposed to this view is, that the removal of the carbonate of lime from the diorite appears more likely than the removal of the other constituents, while the carbonate of lime is left; therefore, the more probable opinion is, that the upper portion of the diorite was gradually decomposed, and that the carbonate of lime was carried down into the lower portions where it was deposited. When the albite was deprived of both its lime and alkalies, clay would remain, and in both the Breitenbrunn and the Bermsgrün beds there is indurated clay.

To the south-east of Raschau there is a bed of white limestone, partly compact, and partly granular. This bed is from one to six feet thick, and on the whole is bedded parallel between the mica-slate, but at some places branches irregularly into it, and contains so many angular fragments of the mica-slate that, in this instance, as in others, there may be a doubt as to the simultaneous production of both rocks.* This doubt becomes greater from the fact, that in the Harnrück mountains, between Ehrenfriedersdorf and Geyer, the limestone occurs as successive strata, bedded alternately with the mica-slate, both masses being so mixed with each other at parts that there is such a gradual transition from one rock to the other that it cannot be distinguished where one ends and the other commences.† At the "Weisser-Adler," also, fragments of the greenstone are remarkably frequent in the limestone and dolomite, and though the irregular junction of the two rocks is quite sharp and distinct, the limestone and dolomite must be regarded as of more recent date than the greenstone.‡ Cotta remarks that these rocks must have been forcibly inserted between the slates, because otherwise, as he considers, the filling of such a narrow space cannot be accounted for. This force must have been exercised by the limestone, and consequently the limestone would, according to this view, be not only of more recent date than the slate, but also more recent than the ore-bearing greenstone, of which it contains numerous fragments.

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* English edition, ii, 287.

Then taking for granted the subsequent introduction of this carbonate of lime, it must have taken place in the liquid state, either melted or in solution.

Hall's experiments § show that a pressure of eighty atmospheres is necessary for rendering the action of heat upon carbonate of lime recognizable, and that to obtain a perfect result a pressure four or five times greater is requisite. He once succeeded in melting carbonate of lime, and it appears to have been in a pasty state like melted sealing wax.

Since there is no ground for the assumption, that at the time this granular limestone in the Erzgebirge and at other places took up its present position, the atmospheric pressure was four hundred times, or even eighty times, as great as at present, we must assume, as Hutton and Hall did, that the protrusion of the carbonate of lime took place under a perfectly closed covering of rock, at least 3,400 or 4,300 feet thick.

Even admitting this assumption, it seems impossible that the melted carbonate of lime could have penetrated into fine fissures and cracks. Hall's experiments also point to other circumstances, of which we find no indication in the proximity of dykes and beds of granular limestone. Thus, for instance, as soon as the carbonate of lime began to soften under the influence of heat, it acted upon the porcelain tables used in the experiment, to such an extent that an easily fusible mass was produced, which penetrated all the small cracks, and spread over the tubes beyond the part where they were in contact with the carbonate of lime. When the tubes were filled with a mixture of powdered carbonate of lime and quartz, combination of these substances sometimes took place, producing a mass that presented distinct indications of fusion.

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* Naumann.—Erläuterungen, ii, 240.

† Ibid. p. 256.

‡ Ibid. p. 243.

§ Transact. of the Royal Soc. of Edinburgh, 1804.

It is evident that the sides of fissures through which it is supposed that the melted carbonate of lime was protruded would have been acted upon to a greater extent than porcelain tubes. Hence it is impossible, according to this view, to account for the fact, that sharp-edged fragments of greenstone and mica-slate should have been imbedded in the carbonate of lime without being melted down by contact with it. Nothing can more clearly illustrate the totally untenable character of this hypothesis of protrusion in a melted state than this simple fact.

I am of opinion that the subsequent introduction of the granular limestone can only be accounted for upon the supposition that it is a product of the decomposition of greenstone, and chiefly of the hornblende that rock contains. It is impossible to conceive this decomposition being effected by igneous action. The conversion of the lime in hornblende into carbonate of lime requires carbonic acid, and this would only be supplied by exhalations from the interior of the earth, or by meteoric water.

Moreover, the beds of diorite in the Erzgebirge contain hydrated minerals—chlorite, talc, picrolite, serpentine, opal, gypsum, iron pyrites—which loses half its sulphur at a moderate heat—as well as galena at the lower parts, and pyromorphite and carbonate of lime at the upper parts. It is quite impossible to account for the production of these different minerals in accordance with the plutonic doctrines.

The ore-bearing deposit at the Taberg, in Greenland, consists of a hornblendic rock situated as an isolated mass in the midst of gneiss. It contains magnetic iron ore, both as veins and intimately mixed with the hornblende and felspar. There is, moreover, greenstone in this mountain similar to that occurring so frequently in Greenland. This greenstone is also surrounded by gneiss, so that the Taberg is correctly regarded as a bed of greenstone highly impregnated with iron ores. Veins of limestone and bitter-spar traverse the mass of the mountain in various directions. The thickest of them have saalbands of green serpentine. The deposits of iron ore in the gneiss at Staf, in Sodermanland, is intimately mixed with fragments of hornblende and granular limestone. The magnetic iron ore of Dannemora is intimately mixed with chlorite, which is accompanied by quartz. Fine-grained limestone also occurs there mixed with grammatite, and not unfrequently traversed by threads of copper pyrites. This limestone contains also small particles of magnetic iron ore; it is also ferruginous, and contains carbonaceous substance. In the deposits of ore at Dannemora and other places, bitumen occurs, partly as superficial drops, and also imbedded in small spherical cavities in the quartz or calc-spar, showing evidently that at these places minerals have been produced in the wet way. In the ore at Nordmarken, grammatite occurs associated with calc-spar and picrolite. Chlorite also occurs there. In the magnetic iron ore of the "Age" mine, there is, besides hornblende, a large quantity of quartz blended with the mass, and sometimes containing imbedded malacolite.*

At Arendal,† hornblende crystals occur imbedded singly in quartz or calc-spar, or attached to the side of cavities in compact hornblende, which appear to have been originally filled with calc-spar. They also occur in the beds of ore, and sometimes in the adjoining rocks. Sometimes, after removing the coating of calc-spar from the crystals, they appear to be covered with a mass resembling steinmark or mountain soap. The compact and crystalline hornblende occurs almost everywhere as a constituent of the rocks adjoining the beds of ore.

If the cavities just mentioned were formerly filled with calc-spar, the subsequent production of the hornblende in the wet way cannot be doubted. The occurrence of hornblende in the rocks adjoining the beds of ore, indicates that the ore has originated from the hornblende, and the decomposed state of these rocks supports the view.

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* Hausmann.—Reise durch Skandinavien in 1806 and 1807. L. v. Buch.—Reise durch Norwegen und Lappland, 1810. W. v. Hisinger.—Versuch einer mineral. Geographie, von Schweden, 1826. G. Sukkow.—Die bedeutendsten Erz. und Geisteinslager im Schwedischen Urgebirge, 1831. Daubree.—Skandinavein's Erzlagerstätten, 1846.

† Weibye in Karsten's und v. Dechen's Archiv. xxii, 465.

In the granular limestone at the "Kaasefjeld" mine, in the island of Langö, Weibye found crystals of albite traversing the calc-spar in all directions, and also talc and tremolite. In another mine octahedrons of magnetic oxide of iron occur in the fine-grained magnetic iron ore, or in the calc-spar blended with it. Such octahedrons also occur in a third mine, separately, in a very fine-grained mixture of hornblende, magnetic oxide of iron, and albite; and near Krägeroe they occur separately, in small cavities of the hornblendic gneiss, partly in drusy cavities of albite crystals; and several, if not all of these cavities, appear to have been at one time filled with calc-spar. Weibye also found magnetic oxide of iron as a coating upon quartz druses. The masses of magnetic iron ore are frequently accompanied by masses of calc-spar, and are in some places detached from the adjoining rocks by masses of trap rocks.

It appears, therefore, that at these places the hornblende is associated with those minerals which have already been shown to be the products of its decomposition, and which, in those instances, have probably the same origin.

The conversion of diorite into chlorite-slate is very distinctly recognizable in the Ural. The underlying bed of the mining works at Schelesinkoi was at one place diorite, with a preponderating amount of hornblende, at another place distinct chlorite-slate. Where the latter rock contains hornblende, the presence of undecomposed hornblende-slate may perhaps be inferred. This is the case with a chlorite-slate near Slatoust, in which there are large crystals of hornblende and small needles of actinolite. The presence of magnetic iron ore in most of the chlorite-slate described by G. Rose,* also admits of the inference that this rock has originated by the alteration of hornblende rock. The crystals of bitter-spar in the chlorite-slate at Beresowsk and Newjansk indicate a partial decomposition of silicate of magnesia, probably that of hornblende. Granular limestone is associated with the chloritic and hornblende-slate only at the mining works at Newinsko-Stolbinskoi. But since it would always underlie the hornblende-slate, if it were a product of the decomposition of that rock, its pre-existence would not always be readily recognizable, except where mining operations are carried on.

Since hornblende is capable of conversion into steatite, and since this mineral is so closely related to talc, it is possible that hornblende-slate may be converted into talc-slate. The occur-

* Reise nach dem Ural, ii, 538.

rence of actinolite in the talc-slate at Kuschtimsk, where the crystals of this mineral closely resemble those occurring in the Zillerthal, and at St. Gotthardt in a similar manner, and at Newinsk, is probably a safe indication that the talc-slate has originated from hornblende-slate. It is remarkable, that at some places the talc-slate is very quartzose, and even contains large beds of quartz, as at Suchowissimsk, Bissersk, and Magdalinskoi-Kamen; for in the conversion of hornblende into talc, silica would not appear to be eliminated. Near Suchowissimsk, beds of chlorite-slate, alternate with very quartzose talc-slate, and both have the same dip as the adjoining hornblende-slate. However much this circumstance may favour the opinion that they have originated from hornblende-slate, it is not the less remarkable that the chlorite-slate is not quartzose, because the conversion of hornblende into chlorite, would be attended with elimination of silica. Near Bissersk, quartz rock, talc-slate, and chlorite-slate alternate with each other in beds that have the same dip, and gradually fall into each other. The upper portions of the Ural Mountains consist of talcose quartz rock, which is bounded on the east by hornblende rock, together with gabbro and magnetic iron ore; on the west by greyish-white marble. In the Magdalinskoi-Kamen, the principal ridges consist of chloritic and talc-slate, which is sometimes remarkably quartzose, while the other ridges, probably, all consist of diorite. In some of the talc-slate there is magnetic iron ore and bitter-spar, as in the chlorite-slate. There cannot be any doubt that in these instances there is a connection between the hornblende rocks and the other rocks, which may probably have originated from the former.

In the States of New York, Connecticut, Massachusetts, and North Carolina,* there are masses of magnetic iron ore, containing various sulphurets, which appear to present great resemblance to the metalliferous deposits of Sweeden. They contain the same minerals, and are also connected with masses of granular limestone, hornblende rocks and serpentine, sometimes also with thick deposits of graphite, as at Raleigh, in North Carolina.†

Such a frequent recurrence of similar phenomena must be ascribed to like causes. Wherever hornblende rocks occur, they are associated with nearly the same products of decomposition.

Daubree remarks rightly that the presence of anthracite in many of the metalliferous deposits of Scandinavia, which are surrounded by gneiss rocks, and the existence of carbonaceous substance in the limestone of Dannemora, renders it probable that these masses are of sedimentary origin.* He mentions the occurrence of ores in intimate mixture with minerals—such as hornblende, augite, epidote, mica, and various zeolites, which elsewhere are met with only in rocks of igneous origin—together with carbonaceous substance and bitumen, as an anomaly; and such it will always appear while it is assumed that these minerals have been produced by igneous action.

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* Mather.—Silliman's Amer. Journ. xxi, p. 97. Hitchcock.—Geology of Massachusetts.—Shepard on Connecticut.

† Olmstedt.—Silliman's Journ. xiv. 230.

Daubree states that in the vicinity of the metalliferous deposits, the gneiss generally passes into micaceous or hornblende-slate, and the metalliferous deposit passes gradually into these rocks or into the gneiss. He supposes that the bitumen and the substances constituting the metalliferous deposits have originated from the distillation of combustible mineral substance, but that the former were deposited before the formation of the quartz and calc-spar crystals in which they are imbedded.

Admitting for an instant the vague conception of such a distillation, it may be asked whether the silica and carbonate of lime are also to be regarded as products of distillation. As this can hardly be the case, they must have been supplied otherwise. But if the carbonate of lime is one of the most recent products, it is inconceivable how the hornblende rock, in the mines of Aaserud and Narverud, with deposits of iron ore above and below it, can have formed dykes in the limestone, or how many of the deposits of iron ore can have been inserted between masses of limestone. In this case, the ores are accompanied by silicates containing lime, such as garnet, epidote, etc.; and, according to Daubree, these have been produced from the carbonate of lime, probably by igneous action. In that case the carbonate of lime would be the older material, and thus we should have to regard it as being at one place the oldest, and at others, the most recent product.

These contradictory results are characteristic of the attempt to account for alteration of minerals and rocks by igneous action. Since the decomposition of silicate of lime, and its conversion into carbonate, may be recognized in the minerals containing this substance, it appears much more natural to infer that silicate of lime is decomposed in the wet way, than to assume that such minerals are produced from carbonate of lime.

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* This opinion is also applicable to the gneiss of the Vosges and other districts. Elie de Beaumont.—Explication de la Carte Géologique de France, i, 514.

With regard to the metamorphism of the sedimentary rocks, from which the gneiss has originated, Daubree does not offer any opinion. It is, however, impossible that it can have been effected by igneous action, as is shown by the unmistakable sequence of the minerals constituting this rock, and the beds lying between it. But Daubree remarks that the sharply-defined granitic veins and dykes which traverse deposits of ore and also the gneiss surrounding them, present more the character of having been produced by secretion than that of injected masses.

It has already been remarked that the metamorphism of gneiss by igneous agency is absolutely inconceivable. But if the sedimentary origin of this rock cannot be doubted, its conversion into a crystalline rock by the action of water may be accounted for. This is also the case as regards the rocks associated with gneiss, and there is no reason to hesitate in regarding the hornblende it contains, or the hornblende-slate into which it passes, as having been produced by the action of water. Only by this means is it possible to account for the facts, that the first products of such alteration should be subject to a long series of further alterations, and that the substances, originally intimately mixed together, should afterwards be separated more and more, until, finally, they give rise to the production of hydrated minerals—such as chlorite, steatite, talc, mica, and even zeolites; of carbonates—such as granular limestone, calc-spar, dolomite, and bitter-spar, and of quartz and iron ores. It is only by this means that a causal connection between lodes or veins and the adjoining rocks, can be conceived, or that such phenomena as the sudden disappearance of the ores in a copper lode, where it passes from diorite into overlying slate, can be accounted for. If the metalliferous minerals in lodes have been extracted from the adjoining rock by the action of water, and if the diorite contains copper, and the slate rocks do not, it is a natural consequence that the ores would be found only in that part of the lode traversing the diorite.

Connection between hornblende rocks, greenstone, and clay-slate.—Although there are many opinions with regard to the mode in which hornblende rocks and greenstone have been produced, all geognosts are agreed that they occur alternating with clay-slate, and are intimately connected with this rock.

Credner[†] describes greenstone, containing patches of hornblende, in the Thuringian Forest which is bedded conformably with the clay-slate. At Lösnitz, Hadlenstein, and Auerbach, in the

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[*] See ante, p. 85.

[†] n. Jahrb. f. Mineral. etc., 1843, p. 276.

Erzgebirge, greenstone occurs as masses presenting conformable stratification with the clay-slate adjoining. At many places the greenstone-slate alternates with the clay-slate as distinct beds, or is surrounded by the clay-slate. Here and there the transition of greenstone-slate into clay-slate may be observed in the case of a grey quartzose-slate, apparently containing some hornblende between the two. There is not anywhere any sign of the penetration of the clay-slate strata by the greenstone.*

In the transition rocks at Wildenfels, the greenstone constitutes the highest peaks, which are situated almost exactly at the boundary of the primitive slates and the grauwacke. The more extensive masses that extend from two of these peaks into the transition series, do not present the same characters of structure and position as the essential members of the transition series. Naumann † remarks, in reference to this point, that the greenstones at other parts of the transition series present the same characters.

Zippe ‡ mentions the occurrence at Kuchelbad of lumps and balls of greenstone enclosed in clay-slate, and the beds and masses of greenstone. Even Naumann § remarks that the hornblende-slate, occurring as regular beds, presents such a doubtful character, that no opinion can be given as to the mode in which it has been produced. He adds, that the occurrence near Rothau, of hornblende and epidote, in a rock containing abundance of fossil remains may, perhaps, be indicative of its production in the wet way.

According to Beyrick's ‖ description of the transition rocks of the Glatz district, hornblende-slate, green-slate, and clay-slate preponderate, and are associated with thin beds of gneiss, mica-slate, and granular limestone. The hornblende-slate is partly a very crystalline mixture of hornblende and white felspar, the hornblende forming layers parallel to the stratification and enclosing the felspar. Among these rocks there are isolated beds or patches where the stratification is less regular and the structure is somewhat granular. Other hornblende rocks, in which the felspar is barely recognizable, are more frequent. These rocks have a slaty crystalline appearance, and are everywhere accompanied by a clay-slate of a greenish colour, which is considered to be intermediate between hornblende-slate and clay-slate, and passes into sound clay-slate of a blueish-black colour. Between the green-slates there is, at many places, a peculiar rock, which presents a gneissoid character, owing the presence of felspar; it does not contain quartz, but is only a confused schistose mixture of mica and hornblende.

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* Friesleben.—Naumann's Erlauterungen, ii, 275.

† Op. cit.

‡ Abhandl. d. k. böhm. Ges. d. Wiss. 5, iv, 17.

§ Lehrb. d. Geogn. i, 744.

‖ Zeitschrift d. deutschen Geol. Zesel. i, 66.

In this instance, the fact that massive rocks do not occur anywhere in the district is opposed to the opinion that hornblende-slate has been produced from clay-slate by igneous action. Beyrich is of opinion that this hornblende-slate alternating with clay-slate, and gneissoid rocks has never been anything else than hornblende-slate. He points out that, in the fossiliferous rocks of the transition series in Germany, hornblende-slate does not occur anywhere, though other rocks, regarded as metamorphic, appear to occur only in the fossiliferous rocks of this series, just as hornblende-slate is confined to those that are not fossiliferous.

Between this view and that which I hold there is but little difference. If the hornblende-slate was produced directly like clay-slate there must have been material of such composition that the crystalline sediment could be deposited. If felspar and hornblende can be produced in the wet way, and of this there is no doubt, then they might be produced as well during the slow deposition of the mass as by the subsequent metamorphosis of that mass. In both cases the principal agent was water; and the only difference between them is, that, in the latter case, the production of the crystalline minerals would have taken place after the elevation of the sedimentary rocks above the ocean by means of the surface water permeating them. The facts that distinct crystals of hornblende sometimes occur at the planes of cleavage in the non-fossiliferous green-slate, and that in mica-slate, which passes into non-fossiliferous clay-slate, the cleavage is quite independent of the cleavage of the mica, and parallel to the stratification of the rock, are in favour of the opinion that these rocks are metamorphic; for, since the penetration of water would be easier at the planes of stratification, alteration would be effected more readily there than in the mass of the rocks. According to this view the metamorphism may have taken place in the ocean.

But whether the substances suspended in sea water are capable or not of crystallizing at the time of their deposition, or whether the sediment becomes crystalline only when, after its elevation above the ocean, it is subjected to the action of surface water, we must in either case determine whether the constituents of the sediment are in such proportion that they can give rise to crystalline minerals.

Clay-slate consists of several silicates, together with remains of disintegrated minerals—felspathic substances, etc. The oxides of iron, the lime and magnesia, are therefore, combined with silica, and generally only a small portion of them with carbonic acid.

It is a very important circumstance that these silicates, whose production in the wet way cannot easily be assumed to take place at the ordinary temperature, occur in sedimentary rocks. There can be no doubt that these silicates formerly existed in larger proportion in clay-slate; for the water of springs rising from these rocks contains the same bases in the state of carbonates; and since the clay-slate is thus subjected to a constant process of extraction the amount of bases must be gradually diminished. Therefore it cannot be inferred from the presence of a small amount of lime in clay-slate that it was equally small at the time the slate was deposited.

The case is similar as regards soda. It is probable that clay-slate always contains at least traces of soda. The preponderance of potash over soda in the water of springs is a rule that has few exceptions. In accordance with the fact that silicate of potash is less readily decomposed than silicate of soda, it might be inferred that the small amount of soda in clay-slate is a consequence of the extraction of soda to a greater extent than potash. The difficulty of accounting for the conversion of clay-slate containing but little soda, into a crystalline rock containing a much larger amount of soda, would be less considerable, if it could be assumed that the slate, at the time of its deposition, contained a larger amount of soda than at the present time. A clay-slate like that at Prague,* containing 1·23 per cent. potash and 2·11 per cent. of soda, might, so far as regards the alkalies, be converted into hornblende-slate.

But there are processes by which the silicate of potash in rocks is converted into silicate of soda,† and therefore it is probable that the chloride of sodium in sea water, or in the water of springs, may convert the silicate of potash into silicate of soda.

Consequently the conversion of a sedimentary rock, such as clay-slate into a crystalline rock, would simply consist in the arrangement of the several silicates existing in the mass into definite compounds, and in the reaction between these silicates and the substances contained in the water permeating it, so that some bases might be removed, and others substituted in their place.

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* See ante, p. 122, No. IV.

† English edition, i, 12.

The change that takes place in a rock is, therefore, similar to that which takes place in a solution containing different salts, the only difference being, that in the latter case the substances that are crystallized were already in existence, while in the former case they are produced from their several constituents. This resemblance becomes still greater when it is remembered that the rock is saturated with water containing in solution the silicates that effect the production and alteration of minerals. The salts present in water, together with the silicates, take no share in the alteration, and are removed in the same manner as the salts that are not assimilated by plants. The carbonates present in water are not passive, but contribute to the decomposition of the silicates in rocks.

The crystallization of felspar, or any other compound silicate, in a rock such as clay-slate, containing the constituents of that mineral, does not in any way differ from the crystallization of the carbonate of lime constituting shells,* except that, in the former case, the production and crystallization of the minerals are simultaneous, and that in the latter case the crystallization takes place more rapidly in consequence of the greater solubility of the carbonate of lime than of silicate of alumina and potash. For the same reason the crystallization of carbonate of lime can be effected artificially, but that of felspar cannot, and, consequently, it is necessary to seek for indirect evidence of its production in the wet way.

When we find crystals of felspar in cavities into which water penetrates with the substances dissolved in it, the production of felspar from solution is as evident as that of the large crystals of quartz occurring in such cavities. There is no question that these quartz crystals have been produced in the wet way, although quartz has not been crystallized in this way artificially.

Comparing the composition of the clay-slate from the "Pferd" mine, near Siegen,† with that of diorite containing 90 per cent. felspar and 10 per cent. hornblende,‡ there appears to be nearly the same relative proportions of silica and alumina, and therefore as regards these two constituents it is possible that the clay-slate might be converted into diorite. It is true the clay-slates do not contain lime, so that their conversion into diorite must have been attended with the introduction of lime or magnesia. If the slates contained the requisite amounts of lime and magnesia, there is, from a chemical point of view, no improbability of this change taking place.

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* English edition, ii.

† See ante, p. 127, Nos. XV. and XVI.

‡ See ante, p. 274.

The remarkably large amount of alkalies in these slates admits of the inference that they have accumulated in the course of time. This may have been due to a reaction between alkaline carbonates and silicates of lime, giving rise to carbonate of lime and alkaline silicates; and since these slates are situated at great distances below the surface, it may be that the water reaching them contains alkaline carbonates, extracted from the upper portion of the slate rocks by the decomposition of alkaline silicates.

The percentage composition of the diorite, containing 80 per cent. felspar, and 20 per cent. hornblende, shows how the amount of alumina decreases, and that of protoxide of iron increases in proportion as the amount of felspar diminishes, and that of hornblende increases. A still larger proportion of hornblende in diorite would bring its composition nearer to that of the clay-slate No. XIV. It short, it is possible that diorite, containing different proportions of its constituent minerals, may be produced from clay-slate containing silica, alumina, and peroxide of iron, in the same proportions as in the slates No. XIV, XV, and XVI, provided the slate also contains the requisite amount of silicate of lime, or that this constituent is supplied during the metamorphism.

In order to ascertain whether there are any sedimentary rocks of such a composition, and containing such an amount of lime, that they could give rise to the production of hornblende rock, I analysed a number of rocks and at last found that the green slates of the transition rocks in the Glatz district, which are intermediate between clay-slate and hornblende-slate had the following composition:—

		I.		
		A.	B.	C.
a.	Carbonate of lime	9·39	..	..
	" magnesia ..	0·25	..	..
b.	Silica	45·66	50·53	47·68
	Alumina	12·33	13·65	12·88
	Protoxide of iron	23·20	25·67	24·23
	Lime	1·69	1·87	7·27
	Magnesia	1·24	1·37	0·42
	Alkalies and water	6·24	6·91	6·52
		100·00	100·00	100·00

		II.		
		A.	B.	C.
a.	Carbonate of lime	13·81	..	..
	" magnesia ..	3·72	..	..
	" iron	0·90	..	..
	Silica	0·05	..	..
b.	Silica	47·73	58·55	52·12
	Alumina	2·64	3·24	2·87
	Protoxide of iron	17·94	22·01	20·18
	Lime	7·82	9·59	16·98
	Magnesia	1·79	2·20	3·92
	Alkalies and water	3·60	4·41	3·93
		100·00	100·00	100·00

I. Greenish slate, near Neuhof.

The dirty green matrix of this rock contained very minute rounded particles of a whiteish or brownish colour, and consisting chiefly of carbonate of lime. It effervesced almost everywhere with acids.

II. Green-slate at Neise-Wehr.

This rock alternates with felspathic or gneissoid green-slate, and effervesces with acid.

Nos. I A, and II A, give the composition of the slates as a whole, *a* being the portions dissolved by hydrochloric acid, and *b* the residue decomposed by carbonate of potash.

	Per cent.
In No. II A, the carbonic acid of the three carbonates amounts to	8·32
The direct estimation gave	6·48
Difference	1·84

Consequently hydrochloric acid had dissolved not only the carbonates, but also decomposed a portion of the silicates of the bases. This is also indicated by the solution of silica by the hydrochloric acid. It cannot be determined whether the iron extracted by the acid was in the state of carbonate. If it existed as peroxide, the above difference would be reduced to .. .. .. 1·50

Correcting No. II A in this way, the amount of carbonates is reduced, and that of silicates increased, especially in the case of lime. Thus the difference of 1·84 per ent. would refer to the alkalies and water which were estimated only from the deficiency, and their amount would be increased to 5·44 per cent. As regards the main object of these analyses this difference is not of any account, and the results serve to show decidedly the presence of silicates of lime, magnesia, and of protoxide of iron in the green-slates.

Nos. I B and II B give the composition of the two slates after deducting the carbonates, and under the assumption that they were infiltrated.

Nos. I C and II C give the compositions after adding the bases of the carbonates to those of the silicates, under the assumption that the carbonates were produced by the decomposition of the silicates. Whichever view may be correct is not of much account, because the doubt extends only to the original composition of the slate, and not to the presence of silicate of lime, etc. The following analyses of the green-slate seem, however, to favour the opinion that the carbonates are products of the decomposition of silicates:—

	III.	IV.
Silica	61·72	54·75
Alumina	19·55	13·48
Protoxide of iron	8·55	14·38
Lime	0·55	6·19
Magnesia	1·08	4·79
Alkalies	4·81	4·61
Loss by ignition	3·74	1·80
	100·00	100·00

III. Primitive clay-state below Rothwaltersdorf.

IV. Very crystalline hornblende-slate at Mittel-Steine.

This rock presented a very altered appearance, and did not effervesce with acids—the former did. Neither of them appeared to contain any quartz.

Five other varieties of hornblende-slate from the same locality either did not effervesce at all or to any sensible extent. It has already been pointed out that hornblende rocks rarely effervesce with acids. Therefore, if the carbonate of lime in these green-slates were a product of infiltration, it would be singular that it does not occur also in the hornblende rocks which frequently alternate with the green-slates, and are undoubtedly permeated by the same water. Copious effervescence with acids appears to be a peculiar characteristic of the green-slates, for another coarse-grained rock occurring between layers of green-slate also effervesced copiously with acid.

There is no doubt as to the purely sedimentary origin of primitive clay-slate. The presence in it of silicates of lime and magnesia would be evidence of the existence of these substances in the sea water, from which it was deposited. But if we only find in clay-slate carbonates of lime and magnesia, they can only have originated from the decomposition of silicates, so that the clay-slate would originally have contained all the silicates requisite for the production of hornblende-slate. If these constituents were present in sufficient amount, hornblende and calcareous felspar might be produced from such material, since the production of these minerals, in the wet way, has been decisively proved. The production of hornblende-slate seems therefore to consist in nothing more than a crystallization of existing silicates, so as to form a mixture of individual minerals. If the silicates of lime or magnesia were not present in the sedimentary mass, or if the amount of these silicates was but small, neither hornblende nor felspar could be produced, and the mass would remain merely a mixture of different amorphous silicates. This would account for the alternation of crystalline and amorphous strata of sedimentary origin.

Both the green-slates, Nos. I and II, are characterized by large amounts of iron. Deducting this constituent, the proportions of silica, alumina, lime, and alkalies in No. I approximate to the composition of the hornblende-slate, No. IV. Comparing the composition of the green-slate, No. I B, with that of the hornblende-slate at Kalvola,* there seems to be such a close resemblance, especially when the 27·54 per cent. peroxide of iron is reduced to its equivalent of 24·81 per cent. of protoxide, that it would be, in fact, chemically identical with the hornblende-slate, supposing the carbonates to be removed.

Since the two green-slates differ so widely in composition, it may be inferred that there are other varieties that do not less closely correspond with the varieties of clay-slate in the Glatz transition rocks. In like manner the composition of the green-slate, No. I C, approximates to that of the hornblende-slate at Miltitz.† Consequently, whether the carbonates were infiltrated, or whether they were originally silicates, the rock would appear in both cases to have had a composition of such a kind that hornblende-slate might be produced from it either directly or by a subsequent process of metamorphism.

The green-slates, Nos. I and II, present a considerable difference in the amounts of silica and alumina, and in other varieties of this slate the amounts of these constituents may be such as to give rise to different kinds of hornblende-slate.

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* See ante, p. 289.

† See ante, p. 289.

It may, perhaps, be objected, that from the similarity of the composition of these green-slates and hornblende-slate, it may be supposed that they originated from hornblende-slate by a partial decomposition. But if this were the case, it might be expected that hornblende-slate would occur, in which the transition into green-slate would be indicated by effervescence with acids. Nothing of this kind has been observed either in the six varieties of hornblende-slate from Glätz, or in those from other localities, and even the hornblende-slate at Weidenthal, containing some carbonate of lime, has no resemblance to the green-slate. Moreover, it has been shown that the alteration of hornblende rocks is of a different character.

All these circumstances, therefore, justify the opinion that the green-slates are of sedimentary origin, and have been subjected in the course of time to considerable alteration by a partial decomposition of their silicates, especially silicate of lime, and are still undergoing the same change. It would be impossible to determine why these slates have not become hornblende-slate. The experience of our laboratories teaches us that sometimes insignificant circumstances facilitate or hinder crystallization, and there is no reason why such influences should not prevail in the production and alteration of minerals and rocks.

Beds of granular limestone occur among the transition rocks of Glätz, not only in the green-slates, but also in the hornblende-slate, and very regular strata of limestone occur alternating with the clay-slate and passing into it. This limestone frequently contains mica, and is associated with rocks consisting of mixtures of mica and granular limestone, and presenting a schistose structure. Since this occurrence of mica is characteristic of the granular limestone in this locality, although there is not within a long distance any rock containing mica, Beyrich infers that the crystallization of mica was facilitated where granular limestone was produced. These rocks have the following composition :—

	I.	II.	III.
Carbonate of lime, containing some carbonate of magnesia	82·10	87·49	29·59
Carbonate of iron	2·59	0·47	2·43
Residue	13·81	12·04	67·98
	100·00	100·00	100·00

I. Granular limestone at Ober-Schmottseifen.

This rock was of a grey colour with whiteish patches here and there, and was traversed by layers of mica in the direction of the schistose cleavage. The residue consisted of very small laminæ of mica with quartz sand.

II. Pale red granular limestone containing greenish mica.

The residue of this rock consisted of mica and quartz.

III. Rock resembling mica-slate.

This rock occurs only near the granular limestone. It effervesces at all parts with acids. After extracting the carbonate of lime a very porous mass remained.

Calcareous mica-slate at other places presents a similar composition. Thus Holger found from 12 to 81 per cent. of carbonate of lime in that of Manhartzberg, and Hitchcock states that varieties of this rock in Massachusetts contain from 50 to 80 per cent.

The situation of granular limestone, as regards the slate rocks in the Glätz district, sufficiently shows that it is of sedimentary origin, either from compact limestone, or by the decomposition of rocks containing silicate of lime. The considerable amount of carbonate of lime in the green slates of this locality appears to favour the latter view. The slate No. II could yield material for the production of a bed of limestone equal to one-fifth its own thickness.

As regards the production of syenite, it may also be assumed either that this rock was rendered crystalline during its gradual deposition, or that the crystalline structure was produced by the metamorphosis, in the wet way, of a sedimentary mass.

Naumann* remarks that in this rock indications of stratification are to be observed only when the felspar crystals are arranged in parallel directions, or when there is an admixture of mica in it. However, numerous instances might be brought forward to show that in the alteration of a rock, by the introduction and extraction of substances, the original stratification may be entirely obliterated. Thus, for instance, in dolomite, a product of the metamorphosis of limestone, the stratification has generally disappeared; and in perfectly schistose beds of hornblende rocks, masses occur in which the structure is granular.

I am far from being disposed to assume that clay-slate is the only rock capable of being converted into syenite. In the absence of more numerous analyses of amorphous rocks, attention may be confined to clay-slate, because it happens to contain the same constituents as syenite, and nearly in the same proportions. Moreover, syenite passes into hornblende-slate, and hence it cannot be supposed that this rock has been produced in a manner totally different from that in which syenite was produced. Even admitting that syenite is of eruptive origin, it is at least certain that it could not have been produced in this manner in the condition it now presents.

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* Geognosie, i, 578.

The following analyses show the relation between syenite and clay-slate:—

	I.	II.	III.	IV.
Silica	70·00	65·00	67·50	60·03
Alumina	12·38	14·58	15·89	14·91
Peroxide of iron	0·17	0·20	5·85	8·94
Protoxide of iron	1·51	1·78	..	..
Lime	3·45	4·06	22·4	2·08
Magnesia	3·46	4·08	3·67	4·22
Potash	3·13	3·69	1·23	3·87
Soda	3·44	4·05	2·11	..
Water	0·56	0·66	1·13	5·67
	98·10	98·10	99·62	99·72

Nos. I and II represent the composition of syenite calculated as above, and Nos. III and IV the composition of clay-slate.

From the great diversity in the composition of syenite and clay-slate, it cannot be expected that in any case the quantitative proportions of the constituents would correspond, but still there is such a general similarity between the above rocks, that there can be no doubt as to the possibility that syenite might be produced where such deposits accumulate in the ocean. It is more easily conceivable that syenite may be produced in the wet way by the metamorphism of an amorphous mass having a composition analogous to that of the clay-slate, because any deficiency might in this way be supplied, and any excess removed.

The sequence apparent in the arrangement of the minerals constituting syenite, though quite inconsistent with the opinion that this rock is of igneous origin, is easily explicable on the assumption that it has been produced in the wet way. The rule which obtains in the crystallization of salts from solution, that the least soluble is separated first, does not obtain in the alteration of rocks, because the minerals that crystallize do not exist in solution. In a rock containing from 60 to 67·5 per cent. silica, like the clay-slates analysed by Frick, Pleischel, and Sauvage,[*] the amount of silica varies about that in orthoclase. But Sauvage found that clay-slate often contains more than one-third as quartz, frequently mixed with fragments of felspar.

These fragments of felspar may be regarded as the nucleus of a fresh production of felspar. They are the only definite minerals present in the rock, and they may be supposed to determine the production of felspar by the combination of the silicates disseminated through it, just as a crystal of any salt immersed in a solution containing that salt determines its crystallization. This view agrees with the fact that in syenite, felspar has crystallized first. The silicate of alumina, found in clay-slate by Sauvage,[†] and containing three times as much alumina as orthoclase, and twice as much as oligoclase, must in being converted into either of these minerals be deprived of two-thirds or one-half of its alumina. More probably, however, this silicate is split up into three different compounds: one, consisting of alumina with three equivalents of silica, being converted into orthoclase; another, consisting of alumina with two equivalents of silica, being converted into oligoclase; and the remainder being converted into hornblende. The alkaline silicates would combine with the two former silicates of alumina, and the remaining silicates would combine with the residue.

The chlorite and other substances[†] found in clay-slate may have been produced during the metamorphism in a similar manner; for since hornblende is capable of being converted into chlorite, it is possible that the opposite change may take place under other conditions. In any case, the metamorphism of clay-slate in the manner above pointed out would be attended throughout with an elimination of silica, or rather an accumulation of quartz. If the quartz existing intimately disseminated through the mass of clay-slate took no share in the metamorphism, it would be merely separated from the other constituents in proportion as the production of felspar and hornblende progressed, until, finally, it occupied the interstices between the crystals of these minerals.

From a chemical point of view it might certainly be conjectured that the quartz separated from the clay-slate mass does not take any share in the metamorphism, because, in the insoluble modification, it seems not to be capable of combining with bases. However, the free silica of the clay-slate is in this state, and still the quartz in syenite is a coherent mass, such as could not originate from pulverulent particles, unless they were cemented together, and, since the analyses of the quartz shows that it contains but an extremely small amount of admixtures, this cementing material could only have been a solution of silica. In this case the metamorphism would seem to have been attended with a partial decomposition of silicates so as to yield this silica, or else the water permeating the rock supplied silica.

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[*] Annal. des Mines. 4, vii. 411. See ante, pp. 122 and 126.

[†] See ante, p. 126.

The different kinds of pseudomorphous minerals after quartz indicate the reality of such changes as those above mentioned. Steatite occurs frequently with the form of quartz, brown iron ore and iron pyrites less frequently. But only one case of this kind is sufficient to show that quartz or silica in the insoluble condition may be removed by water. Consequently, it cannot be doubted that, in the conversion of clay-slate into a crystalline rock, the particles of quartz take an active part as well as the other constituents. The possibility of this change taking place is important, because it affords a possibility of conceiving how minerals containing a large amount of silica may be produced in a quartzose sedimentary rock, although the silicates it contains, like those found in clay-slate by Sauvage, contain only one-third as much silica as orthoclase. By such a metamorphism the amount of quartz would be reduced, and that of felspar increased, provided the requisite bases were present in the rock or were supplied by water. The action of water in the production of quartz, not only in syenite, but also in granite and other quartzose rocks, is likewise indicated by the circumstance that the colour of this quartz is due to the presence of organic substance, since it becomes colourless when ignited.

It need not be particularly pointed out that clay-slate may be converted into syenite free from quartz as well as into quartzose syenite. Since clay-slate sometimes presents a composition that admits of its conversion into diorite, the conversion of such a rock into syenite is the more readily conceivable; because a smaller proportion of silicate of lime would be required in the latter case. Clay-slate free from quartz,* or in which the amount of silica did not exceed 64 per cent., would be especially adapted for conversion into syenite free from quartz.

Beyrich† is of opinion that the schalstone and greenstone of

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* See ante, Nos. XIV, XV, and XVI, p. 127.

† Beiträge zur Kenntniss der Versteinerungen des Rheinischen Uebergangsgebirges, 1837, i, 11.

Nassau are of more recent date than the elevation of the schistose rocks, since they have had little influence on the general configuration of the district and the formation of valleys. He compares the origin of the greenstone with that of the more recent basalt and trachyte of the Rhenish districts which have not penetrated the slate rocks.

Oppermann describes schalstone as consisting of clay-slate, chlorite, and calc-spar, in great variety, and always stratified.* It always appears intimately connected with greenstone, more as regards their geognostic relation than from the actual passage of the one into the other, and is still more intimately connected with the strata of the transition series. Beyrich regards it as a transition rock metamorphosed by heat. Limestone appears to have contributed largely to its production, and it often contains fossils corresponding with those in the limestone adjoining; but at the junction of the two masses the outlines of the same fossils are recognizable. In proportion as the amount of iron in the rock is greater, the more distinct are the fossils until, in the red hematite itself, they may be easily detached. Beyrich also mentions transition limestone at Oberscheid, near Dillenburg, containing peculiar fossils, and intimately connected with deposits of iron ore, generally in layers conforming with grauwacke, while the limestone occurs only as unconnected sporadic masses continuous with the iron ore. The overlying bed of this iron ore is greenstone or schalstone, and the underlying bed schalstone. At one place all three of these rocks are considerably and conformably contorted.

In the vicinity of Brilon the red hematite, that is sometimes very quartzose, passes very gradually at many places into limestone that is generally very ferruginous. The junction is similar to that of two wedges. The hematite contains numerous fossils, consisting at the interior of the same kind of hematite that they are imbedded in. The adjoining limestone does not generally contain the same fossils as the hematite, and, on the contrary, the homogenous mass does not present any vestige of organic remains.†

v. Dechen‡ states, that the schistose, or breccia-like schalstone, near Brilon is full of calc-spar fragments and veins, sometimes of extreme tenuity. The whole mass of the rock effervesces with acids. In the most calcareous varieties the grey granular limestone is rendered schistose by pale-green laminæ of clay-slate. Even the schalstone that is not calcareous, and does not effervesce with acids, contains patches of calc-spar as well as black patches of chlorite. One of the beds of green-coloured slate is traversed throughout by veins of white and red calc-spar, another of a yellow colour, contains small particles of red calc-spar; and another bed is very like ordinary grauwacke; its lines of cleavage presenting thick layers of iron ochre. v. Dechen found in it the impression of a *cyathophyllum* similar to those of the adjoining slates. Hence, it may be inferred, that the origin of the schalstone was decidedly the same as that of the grauwacke.

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* Ueber Schalstein und Kalktrapp. Marburg, 1836.

† F. Römer.—Das Rhein. Uebergangsgeb. 1844, p. 39.

‡ Archiv. für Min. etc. xix. 515.

On the other hand, the presence of distinct crystals of white labradorite, situated near small masses of granular limestone, or between patches of black clay-slate, indicates the connection of the schalstone with the schalstone porphyry and labradorite rock. At another place the rock is calcareous throughout, it containing detached blocks of limestone and small particles of iron pyrites. Siliceous-slate and hornstone are also associated with the schistose and calcareous rocks, which are traversed by veins of reddish quartz. Another of these beds which is schistose, porous, and of a yellowish-grey colour, has been deprived of the whole of its lime, and is apparently much weathered.

The schalstone porphyry resembles ordinary schalstone in consisting of a yellowish-green schistose matrix containing irregular granules of calc-spar, sometimes covered with almost black chlorite, which, where the calc-spar has been removed, is converted into iron ochre. Imbedded in this rock are detached crystals of felspar with sharp outlines. The underlying rock of the Enkenberg hematite consists of very marked schistose rocks, with small patches of calc-spar, minute granules of chlorite, and brick-red felspar crystals. The underlying rock of the Grottenberg hematite is a dark-green schistose rock that effervesces copiously with acid at every part, and contains, together with much calc-spar, a large number of well developed brick-red felspar crystals. Similar rocks containing felspar crystals also cccur above a bed of red hematite.

The labradorite porphyry generally contains detached nodules of calc-spar, and is sometimes traversed by veins of calc-spar. It effervesces throughout with acid, and sometimes very small needles of labradorite are imbedded in the calc-spar. It also contains quartz, as veins and nodules, sometimes accompanied by asbestos. Veins of epidote occur several inches thick, with labradorite crystals at the edges. Chlorite and serpentine are both very frequent. Labradorite crystals of all sizes occur in all the varieties; and in some instances, when the rock contains much carbonate, are very soft. Augite crystals occur only in one variety; in another, granules of augite and magnetic oxide of iron. The schalstone porphyry contains large flesh-coloured crystals of felspar imbedded in a matrix, with a very indistinct schistose structure, and highly impregnated with carbonate of lime. Connected with this is a much decomposed yellowish-grey schistose rock without any carbonate of lime, but with green and reddish patches that seem to have been labradorite crystals.

The schalstone in the Harz is described by Hausmann as presenting schistose structure in different degrees. Its green colour appears to be due to chlorite, which is disseminated throughout the mass unequally; and while the matrix of this variety resembles chlorite-slate, that of some other varieties resembles talc-slate. These latter are generally impregnated with oxide of iron, and contain calc-spar and brown-spar, sometimes as small flattened nodules, surrounded with earthy chlorite. In the place of calc-spar, nodules of granular limestone sometimes occur, and the mass passes gradually into pure limestone. The intimate connection between greenstone and schalstone is recognizable in the Harz as well as in the Nassau district.

In the Feldbach wood, near Dillenburg, there is a bed of clay-slate three feet thick, with beds of greenstone six feet thick on both sides. Near Burg a very distinctly stratified greenstone is opened by a quarry. It constitutes the underlying rock of a very thick mass of clay-slate. Then follow slates in contact with fine-grained greenstone, then grauwacke, micaceous clay-slate in beds of three or four inches in thickness. It is impossible to imagine that these beds of greenstone have been injected in a melted state between the beds of grauwacke, for there are no signs of the action of heat at the line of contact between them. Sometimes there is a mass resembling hornstone between the two rocks, but this is merely silicified slate produced by infiltration of siliceous water. The occurrence of this mass is evidence of alteration in the wet way, and it was probably connected with the production of the greenstone.

Some little distance from Erdbach there is transition limestone containing fossils of the posidonia-slate, and in contact with greenstone. Between these rocks there is no vestige of alteration, the line of contact being extremely sharp. This could not have been the case had melted greenstone come in contact with the limestone. The greenstone here is full of white patches of calc-spar, and is traversed by veins of reddish-brown limestone, similar to that with which it is in contact. These veins, some of which are extremely thin, cannot have been formed at the same time as the calc-spar, or they would be colourless. Consequently, they must have been filled up during the production of the greenstone; and as the limestone is unquestionably a sedimentary rock, the greenstone must be so likewise.

The alternation of limestone and greenstone is very marked in some places. Between Erdbach and Medenbach fragments of limestone are imbedded in the greenstone, and contain small particles of greenstone. Below Erdbach the limestone contains imbedded fragments of greenstone, some quite microscopic, others several lines in diameter. By the action of hydrochloric acid these particles are exposed, and by the aid of a magnifying glass small veins and patches of the same red-coloured carbonate of lime are recognizable in the greenstone. In this case there is no possibility of supposing that the greenstone has been injected in a melted state, but, on the contrary, it is evident that there has been an often-repeated alternation in the deposition of limestone and greenstone.

Since there is no appearance of any action of the greenstone upon either the slate or the limestone, it cannot, even if it was melted, have taken the place of previously existing grauwacke strata. Consequently, where rocks appear to have been displaced from their arrangement with the slate, this cannot have been effected by the greenstone.

All these facts, and various others pointed out by v. Dechen, such, for instance, as the occurrence of labrador porphyry in the midst of a stratum of limestone, are opposed to the opinion that greenstone is of eruptive origin. These rocks have certainly been produced in the same manner as the limestone and slate strata with which they alternate, whether the crystalline character was assumed directly in the deposition from the sea, or whether it was produced subsequently by metamorphism.

In order to obtain some data as to the mode in which schalstone has been produced, several specimens of this rock were digested for several days in dilute hydrochloric acid, and then washed. After the carbonate of lime was removed by this means, the residual masses were compared with corresponding unaltered fragments, then powdered, and again digested with acid to separate the remainder of the carbonate of lime. The carbonate was estimated from the decrease of weight, and the peroxide of iron was estimated directly. The substance thus extracted from the whole fragments is represented by *a*, and that extracted from the powder by *b*.

	I.	II.	III.	IV.	V.	VI.
Carbonate of lime *a*	25·98	27·33	32·08	7·14	35·41	1·66
„ „ *b*	6·38	3·57	9·49	15·07	4·46	25·57
Protoxide of iron	1·50	3·19	3·69	7·67	7·80	3·16
Residue	66·14	65·91	54·74	70·12	52·33	69·61
	100·00	100·00	100·00	100·00	100·00	100·00

In all these rocks the carbonate of lime was mixed with some magnesia. The iron in I and II was for the most part, if not wholly, peroxide; in III, IV, V, and VI, as carbonate chiefly.

I. Schalstone from the Feldbach wood, near Dillenburg.

Compact, with a coarse schistose structure, and reddish-brown coloured at the cleavage surfaces. The carbonate of lime was apparently disseminated in patches and thin veins. After treatment with acid it was rather darker coloured, but slightly porous, and was traversed by very thin fissures, even in pieces only a quarter of an inch thick. The cleavage planes and straight fissures indicate clay-slate in which the protoxide of iron had been converted into peroxide.

II. Schalstone from the same locality.

This had a schistose fracture, was reddish brown, with a few greenish patches, probably consisting of unaltered rock. Very fine veins of carbonate of lime were rare. After treatment with acid the colour was much lighter. Very few microscopic pores were recognizable. This rock, like the former, was undoubtedly an altered clay-slate.

III. Schalstone from the vicinity of Dillenburg.

Reddish-brown matrix, with roundish patches of white limestone. It was not schistose, and broke under the hammer into irregular fragments. This rock had quite the character of a decomposed crystalline rock. After treatment with acid it was dirty yellowish-white, very porous, and presented detached reddish and more rarely greenish patches, evidently the products of the decomposition of a mineral containing protoxide of iron, perhaps augite.

IV. Schalstone from the vicinity of Weilburg.

Dirty green, with white patches, perhaps decomposed labradorite. This was probably decomposed greenstone, with carbonate of lime originating from decomposition of silicate of lime. After treatment with acid the surface was almost white, and the interior pale greenish.

V. Schalstone from Wartenberg, near Bredlar.*

The greenish-grey fine-grained matrix contained numerous patches of calc-spar of various forms, and with a reddish tinge; it was partially traversed by veins of calc-spar like marble. After treatment with acid it was dirty yellow, with many drusy cavities, some of which were quite filled with a white mass, probably decomposed labradorite. A small yellow-coloured stalactite, probably of quartz, projected into one of those cavities.

Another specimen of schalstone, contained, in the greenish-grey, fine-grained, and homogenous matrix, some rounded particles of calc-spar, some of which were a quarter of an inch diameter.

Both these rocks were certainly nothing else than very much decomposed greenstone; for clay-slate would not contain so many drusy cavities, though this might be the case with a crystalline rock, in consequence of the removal of minerals.

VI. Schalstone from Rübeland, in the Harz.

This was probably a fine-grained greenstone, with some carbonate of lime originating from decomposed silicate of lime. The colour was considerably removed by acid, but the mass was not rendered at all porous.

These experiments show that clay-slate, as well as greenstone, may be converted into schalstone, and that the amount of carbonate of lime mixed with it varies very much. In the conversion of clay-slate into schalstone the carbonate of lime must be infiltrated, since, with the exception of green-slate, it does not contain any silicate of lime, or only a very small amount. In the conversion of greenstone into schalstone, a portion at least of the carbonate of lime originated from the silicate of lime in that rock. The carbonate of lime in IV and VI, which probably are not true schalstone, certainly originated in this way. The infiltrated carbonate of lime may have been partly derived from overlying strata of greenstone undergoing decomposition, partly also from the beds of transition limestone, which in Nassau, for instance, are situated near at hand.

It is worth noticing, that hydrochloric acid extracted but very little carbonate of lime from the fragments IV and VI, while very much more was extracted from their powder. This was a consequence of the compact character of the rock, and the absence of schistose structure. The existence of the carbonate of lime within the mass presupposes that water has penetrated into it, whether the carbonate of lime is a product of decomposition or of infiltration. If hydrochloric acid had acted upon the mass as long as the water that effected the decomposition of silicate of lime, or the deposition of carbonate of lime, there can be no doubt that the whole of the carbonate would have been extracted.

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* v. Dechen.—Archiv. xix. 468.

When the carbonate of lime in schalstone is situated in parallel layers or veins, like the quartz veins in clay-slate, and is not imbedded in the mass; when after treatment with acids the mass presents no recognizable porosity, and especially when the presence of carbonate of lime is recognizable only by effervescence with acid, it may be inferred, with great probability, that the rock from which the schalstone was produced was clay-slate. The schalstone containing fossil remains can only have originated from sedimentary rocks. But when, on the contrary, the carbonate of lime appears as imbedded masses, or as irregular veins, as in marble, and when there appears to be some connection between the rock and the labrador porphyry, as is the case in the Brilon district, it may be concluded, with great probability, that the schalstone had originated from greenstone by alteration. It is obvious, also, that the water by which the rock has been permeated, and from which carbonate of lime has been deposited, has at the same time produced considerable further alteration, having in the case of greenstone obliterated the crystalline structure of the mass, and in the case of clay-slate effected the conversion of protoxide of iron into hydrated peroxide.

The analysis of transition limestone from near Erdbach shows that it contains 28·62 per cent. clay-slate mass; and if so much of the carbonate of lime were removed from it that the proportion of clay-slate mass became the same as in the schalstone I and II, it is possible that in this way schalstone might be produced. But in that case the bulk of the limestone would be very considerably reduced. The above-mentioned schalstone, which is situated in the same general direction as the limestone strata, may possibly have originated in this way.

In the Brilon district, the limestone strata do not present a regular continuity, but are contorted, passing into clay-slate, and sometimes altogether disappearing. If under such geognostic conditions the clay-slate is converted into schalstone, a change that would be facilitated by the proximity of limestone, it might appear that this schalstone was altered limestone.

On the Michelstadt road, near Darmstadt, there is a greenstone rock that was formerly quarried. The interior of the mass is greenish, the exterior reddish-brown; it very readily crumbles to a reddish-brown earth, and is abundantly traversed by perpendicular veins of heavy-spar. In one of the quarries the rock presents an amygdaloid appearance, the cavities containing carbonate of lime. When a fragment of this rock is immersed in hydrochloric acid, it is evident that the matrix contains throughout carbonate of lime, and consequently that it is undergoing decomposition. After dissolving away the carbonate of lime in the cavities, there remains a greenish-white mineral, partly in small drusy cavities, and partly as an incrustation. This rock, which is imperfectly stratified, presented some resemblance to schalstone; it is traversed by a number of vertical heavy-spar veins several inches thick, and is covered with a layer ten or fifteen feet thick of fragments that have been partially converted into a reddish-brown earthy mass.

The clay-slates containing carbonates, already referred to,* have some analogy with schalstone.

The above-mentioned origin of the carbonate of lime in schalstone is rendered probable by the analysis of altered labradorite crystals from the greenstone at Dillenburg.† Notwithstanding the presence of admixtures of augitic substance in these crystals, it was possible, by comparative analyses of the unaltered, partially, and wholly altered crystals, to ascertain the character of the alteration, as regards the production of schalstone, and whether the carbonate of lime in it might not originate, in part, at least, from the decomposition of labradorite; the effervescence, not only of the crystals, but also of the whole mass of the rock,‡ shows that these, as well as the probably augitic admixtures, yielded carbonate of lime for the production of schalstone.

The decomposition of the silicate of lime in labradorite may take place so that part of the lime is removed as carbonate, and part as silicate; the presence of silicate of lime, together with carbonate of lime in the water of springs, and the above-mentioned elimination of silica, are indicative of such an alteration. Moreover, it must not be overlooked that in the simultaneous decomposition of labradorite and augite, constituting in a state of intimate mixture the matrix of a rock, the products may be different from those yielded by each mineral separately.

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* See p. 130.

† English edition, ii, 207.

‡ See ante, p. 333.

I believe that the above facts and remarks are sufficient to show, beyond possibility of question, that the igneous origin of greenstone cannot be entertained, and consequently that the labradorite crystals can only have been produced in the wet way.

As regards the production of schalstone, the analysis of the altered labradorite crystals shows that this constituent of greenstone would alone yield a very considerable amount of carbonate of lime, according to the analysis 15·6 per cent. To this is to be added the carbonate of lime from the augitic constituent of the rock. Consequently schalstone that, like the one above mentioned,* does not contain such large amounts of carbonate of lime, may have derived the whole of it from the decomposition of silicate of lime.

The intimate connection between limestone and red iron ore is extremely interesting, since it shows how diversified the alterations have been that took place in the grauwacke rocks. In the Brilon district also, there is a remarkable connection between the labrador porphyry and amygdaloid rocks, and the red hematite beds which occur only together with those rocks. At some places the amygdaloid rock is completely surrounded by deposits of red hematite, and sometimes this mineral occurs in the midst of the amygdaloid rock.

The connection between the limestone and red hematite induced me to make the following analysis. The connection between the labrador porphyry or amygdaloid rocks and iron ores has been already referred to.† Beds of iron ore cannot, however, occupy the space of the previously existing labrador rocks; for the silicate of alumina could not be extracted from this rock without the other silicates, but more probably the bases of these silicates have been extracted, and again deposited at other places.

I. Reddish-brown transition limestone from Erdbach.‡

Extracted by hydrochloric acid:—

Carbonate of lime	82·19	
„ magnesia	1·50	
Peroxide of iron	0·28	
	——	83·97

Residue melted with carbonate of soda:—

Silica	9·23	
Peroxide of iron	5·56	
Sesquioxide of manganese ...	0·33	
Magnesia	0·35	
	——	15·47
		——
		99·44

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* See ante, p. 333. No. V.

† English edit., ii., 405.

‡ See ante, p. 332.

Just as in this analysis hydrochloric acid dissolved the carbonates and left the silicates, so would the carbonated water permeating the mass. The peroxide of iron in the hydrochloric acid solution was probably in the state of carbonate of iron in the rock. The insolubility of the residue in acid showed that it consisted in part, at least, of silicates; but it also contained granules of quartz.

Such a limestone would, after the extraction of the carbonates by water, yield a very siliceous red hematite, containing a considerable amount of manganese. By this alteration, the original mass would have been diminished to the extent of 84 per cent. But if at the same time carbonate of iron was dissolved in the water that produced the alteration, it might have been deposited in the place of the carbonate of lime removed, since carbonate of lime is displaced by carbonate of iron.* This carbonate of iron would have been converted into peroxide, and would have cemented together the siliceous oxide of iron, converting the whole into quartzose hematite.

If the beds of red hematite that pass gradually into highly ferruginous limestone have originated in this way, it follows that if the red hematite originated solely from the oxide of iron in the limestone, and if this did not contain more than the above limestone, the beds of red hematite would be very much less in bulk than the original limestone. The above-mentioned circumstance, that the outlines of the fossil remains in the limestone are more distinct in proportion as this passes into red hematite,† may be a consequence of the extraction of carbonate of lime.

The production of iron ores from limestone is most probable in localities where they are considerably traversed by masses of limestone, as in the thickest bed of iron ore at the Grottenberg, in the Brilon district, where sometimes three-fourths of the whole mass must be broken away. Altogether, the iron ores in this locality are highly calcareous where they occur in thick beds. In Nassau, also, the calcareous iron ore often occurs in very thick masses, while that containing quartz or the pure red hematite occupies comparatively small spaces. Perhaps, in the formation of these masses of iron ore, the peroxide of iron, formerly mixed intimately with the carbonate of lime, was separated from it at places; perhaps, also, the deposition of the oxide of iron took place separately.

It is worth noticing that the residue left by the action of

* See under "carbonate of iron," chap. lx.

† See ante, p. 329.

hydrochloric acid upon the transition limestone in the above analysis, is a silicate consisting of peroxide of iron, sesquioxide of manganese, and magnesia; for hence it follows that there is a possibility of the production of crystalline silicates—such as those constituting the masses of greenstone in the transition limestone—from the mass of the limestone itself, in case the deficiency in other silicates was supplied by infiltration. The ferruginous quartz, and other quartz that accompanies the red hematite in some places, probably originates from this admixture.

A blueish-grey transition limestone that occurs near Erdbach, in contact with the fossiliferous slate, contains a brown layer from half an inch to an inch thick, which is parallel with the stratification, and is closed in at one side by the limestone. A strong smell of chlorine was given off when a piece of this rock was immersed in hydrochloric acid, showing the presence of superoxide of manganese. By treatment with hydrochloric acid, it gave the following results:—

II. Transition Limestone.		II B. Brown Stratum.	
Carbonate of lime	65·33	..	1·66
„ magnesia	1·23	..	2·39
„ iron	2·39	Peroxide of iron	5·38
„ manganese	0·83	Sexquioxide of manganese	0·24
Silica	..	..	0·73
Dark grey clay-slate mass insoluble in hydrochloric acid	28·62	..	28·62
Water and loss	1·60	..	..
	100·00		39·02

The clay-slate substance retained the form of the pieces of limestone. There can be no doubt that the brown stratum originated by the abstraction of greater part of the carbonate of lime and peroxidation of the iron and manganese in the limestone. The constituents of this brown stratum were estimated upon the assumption that the portion insoluble in hydrochloric acid had not been reduced by the alteration of the limestone. However, the presence of silica in the hydrochloric acid solution showed that at least a part of this substance had been converted into silicates decomposable by the acid. A part of the peroxide of iron and magnesia in B may have originated from the decomposition of such silicates, and this is the more probable since the residue of B was almost white, while that of A was dark brown, and also since the proportions of iron and magnesia in the soluble portion was greater in B than A. The diminution of bulk that must have taken place in this alteration corresponds with the friable and porous character of the brown stratum.

Even if the above observations really represent the nature of the conversion of transition limestone into red hematite, the product in the above case would only contain 14·4 per cent. of manganiferous oxide of iron. But transition limestone, containing a much smaller amount of substance insoluble in acids, would yield richer iron ores, such as occur in the neighbourhood of Dillenburg. As regards this alteration, it is a matter of indifference whether the limestone contains iron and manganese only as carbonates, as is the case in II, or whether these metals exist as oxides, as in I; for in the former case the carbonates would be peroxidized during the alteration, and in the latter the oxides would remain unaltered.

If red hematite has originated in this way from limestone strata; if schalstone is, in part at least, clay-slate that has been impregnated with carbonate of lime, it is very natural to suppose that the same carbonate, removed in the former case, was deposited in the latter. Such a transposition of the material of strata must have been attended with disturbances of the stratification.

When it is remembered that the sinking of the ground in limestone districts is a consequence of the removal of carbonate of lime by water, that, for instance, the springs of the Pader district carry away in sixty-seven days a quantity of carbonate of lime sufficient to produce a sinking of 150 feet diameter and 25 feet deep, some idea may be formed of the magnitude of the transposition of material effected by this means.

The extensive hollow spaces in the limestone of the Illyrian and Dalmatian coasts, which sometimes seem to be several miles long, and the funnel-shaped depressions of the surface of these mountains, are instances of this kind. Even the deep basin, at the bottom of which are the mercury mines of Idria, appears to be an unusually large depression produced in the same way. The discharge of considerable masses of water from the funnel-shaped depression at the bottom of the Zirknitz lake, after long-continued rain, is sufficient to cover a surface four miles long and a mile wide, and shows the extent of these subterranean cavities.*

When a bed of limestone is washed away more at one part than

* II. v. Gansauge.—Poggend. Annal. li, 291.

at another, local subsidence takes place, and the overlying strata are removed from their former position. I am far from supposing that this action has been the only cause of the tilting of entire mountain ranges, but it cannot be doubted that it has produced partial displacements of strata. This may probably have been the cause of the arrangement of the strata in the Brilon district, where, contrary to the general rule, the beds of red hematite are situated under the amygdaloid rocks and the schalstone.* The general superposition of the red hematite beds on the schalstone favours the opinion that they have originated from limestone strata by the removal of their carbonate of lime, which has contributed to the conversion of the clay-slate into schalstone. The fact that, in Nassau, the beds of red hematite undergo frequent displacement, is shown by the fissures which traverse them, and are generally filled with a decomposed mass of schalstone. Alternate elevations and depressions, producing alterations in these beds, so that the oxide of iron extends further into the schalstone, are also frequent.†

CHAPTER LVI.

MICA-SLATE, CHLORITE-SLATE, AND TALC-SLATE.

THE frequent occurrence of mica-slate, presenting a distinctly recognizable transition into clay-slate,‡ is sufficient ground for the inference that both kinds of slate have a similar composition, and that mica-slate is merely clay-slate in which the constituent minerals have assumed a more distinct crystalline condition.

Mica-slate being essentially a mixture of mica and quartz, not always very uniform, there is much difficulty in determining its composition. Fortunately, however, it is only necessary to estimate the bases in mica-slate in order to institute a comparison between it and clay-slate, for it is most probable that in the conversion of clay-slate into mica-slate the quartz of the former rock remains in the mica-slate, and since in clay-slate the quartz is intimately mixed with the mass of the clay-slate, it would be mixed with the mica in the altered rock. But the layers of quartz in mica-slate cannot have been present in the original clay-slate, and must have been produced in the same manner as the quartz in veins and dykes in clay-slate by the decomposition of silicates.

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* v. Dechen, op. cit. p. 532.

† F. Sandberger, op. cit. p. 36.

‡ Naumann.—Op. cit. p. 742.

If it were possible to effect a complete mechanical separation of the quartz from the mica-slate, the separate analysis of the mica would furnish the most useful results. In some instances, where the mica can be crumbled between the fingers, it is possible to approximate somewhat to such a separation, and the silica obtained in the analysis belongs almost entirely to the mica. But in many instances this cannot be done.

In analysing some specimens of mica-slate the method adopted was, after drying at 212° F., and estimating the loss by ignition, to digest for twenty-four hours with sulphuric acid, and then to decompose the residue by means of hydrochloric acid. These two portions of the slates were analysed separately, and the constituents extracted by sulphuric acid are marked A, those of the residue B, and the composition as a whole C.

The portion extracted by sulphuric acid always contained protoxide of iron, and its amount was probably greater than that of peroxide, although during the digestion with acid it would be partially peroxidized. The whole amount of iron was, however, estimated as peroxide, because the estimation of the relative proportions of the two oxides was not essential for the purpose of these analyses. The number representing the amount of iron also includes the manganese, and the loss by ignition comprises a portion of the fluorine. The silica generally did not gelatinize, but remained as a granular mass, containing some shining laminæ. By ignition these sometimes became pale yellowish, and lost their lustre.

I. Blueish-grey mica-slate of the Zillerthal.

	C.
Silica	55·15
Alumina	12·56
Peroxide of iron	16·94
Magnesia	10·99
Potash	2·16
Soda	1·24
Loss by ignition	2·13
	101·17

II. Mica-slate of Liebethen, in Hungary.

	A.	B.	C.
Silica	..	..	52·01
Alumina	9·36	4·28	13·64
Peroxide of iron	14·08	5·64	19·72
Lime	0·67	..	0·67
Magnesia	3·61	1·81	5·42
Potash	1·98	3·57	5·55
Soda	0·10	0·45	0·55
Loss by ignition	..	..	2·49
	29·80	15·75	100·05

This slate is separable into very thin laminæ, and is traversed by layers of quartz. The amount of magnesia in this slate seemed to admit of the conjecture that it might be entirely decomposed by repeated digestion with sulphuric acid, but it was found that in proportion as the amount of silica was increased, the extraction of the bases was effected more slowly.

	1st Portion.	2nd Portion.	3rd Portion.	Residue.
Alumina Peroxide of iron	23·12	2·17	trace	1·24
Potash	..	..	..	0·34
Natron	..	..	..	0·03
				1·61

The residue was decomposed by hydrofluoric acid.

III. Mica-slate of Bräunsdorf, in Saxony.

Analysed by Kjerulf.

	A.	B.	C.
Silica	..	..	48·72
Alumina	16·02	5·78	21·80
Peroxide of iron	11·35	4·17	15·52
Magnesia	1·22	0·06	1·28
Potash	2·32	2·14	4·46
Soda	0·80	1·43	2·23
Loss by ignition	..	..	5·26
	31·71	13·58	99·27

Analysed by

IV. Mica-slate containing garnet at Orawitzee, in the Bannat.

Kjerulf.

	A.	B.	C.
Silica	..	..	50·88
Alumina	23·85	3·11	26·69
Peroxide of iron	7·47	1·01	8·48
Magnesia	1·01	0·18	1·19
Potash	3·48	1·04	4·52
Soda	1·56	1·16	2·72
Loss by ignition	..	..	4·19
	37·10	6·50	98·67

Analysed by Kjerulf.

V. Mica-slate of Tagilsk in the Ural.

	A.	B.	C.
Silica	..	..	56·99
Alumina	17·86	1·12	18·98
Peroxide of iron	8·49	0·53	9·02
Lime	4·90	..	4·90
Magnesia	0·66	0·09	0·75
Potash	2·12	0·87	3·00
Soda	1·50	1·09	2·59
Titanic acid (impure)	..	..	0·91
Loss by ignition	..	..	2·48
	35·53	3·70	99·62

The quartz could not be entirely separated from this slate.

VI. Silver-white mica-slate, containing garnet, at the Arlberg-Tyrol.

	A.	B.	C.
Silica	..	..	58·37
Alumina	10·67	8·36	19·03
Peroxide of iron	8·55	4·74	13·29
Lime	trace	..	trace
Magnesia	0·27	trace	0·27
Potash	0·88	2·08	2·96
Soda	0·55	0·72	1·27
Loss by ignition	..	..	4·81
	20·92	15·90	100·00

This slate presented greenish and yellowish patches. It was separable into thin laminæ, and contained some blackish-green hard lumps, which crumbled under the hammer. Between the layers of mica quartz was not recognizable.

VII. Mica-slate of Innspruck.

	A.	B.	C.
Silica	..	..	81·49
Alumina	1·35	4·68	6·03
Peroxide of iron	5·50	..	5·50
Lime	0·63	..	0·63
Magnesia	1·05	trace	1·05
Potash	0·09	0·74	0·83
Soda	0·09	1·08	1·17
Loss by ignition	..	..	2·89
	8·71	6·50	99·59

This slate effervesced copiously with acid. It could not be separated into thin laminæ, because it was very fine-grained and quartzose.

VIII. Rock resembling mica-slate at Ober-Schmottseifen, after deducting the carbonates of lime and iron.

Silica	51·82
Alumina	15·60
Peroxide of iron	18·79
Lime	3·66
Magnesia	1·77
Alkalies, etc. (by deficiency)	8·36
	100·00

It has already been pointed out* that magnesian-mica may be converted into potash mica. The residue left by the mica-slate, No. II, after being digested four times with sulphuric acid, contained alkalies, alumina, and iron, nearly in the same proportions as potash mica. In the alteration of rocks carbonic acid acts less energetically than sulphuric acid, and the decomposition would cease when magnesia and a portion of the iron had been extracted. Meanwhile no potash would be extracted, because the silicate of potash is not decomposed by carbonic acid, and this agrees with the greater proportion of potash in potash mica than in magnesian mica, and with the relatively larger amount of silica in the former.

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* English edition, ii, 260, 367, 371, 405.

It appears from the above analyses, that in mica-slate, as in mica itself,[*] there is not any definite relation between the oxygen of the bases containing one equivalent of oxygen, and that of the bases containing three equivalents. Taking the oxygen of the former as unity, the proportions of the oxygen in the latter are:—

I.	2·18	V.	4·06
II.	3·61	VI.	13·84
III.	8·11	VII.	4·34
IV.	7·73		

This calculation is made upon the assumption that the iron exists as peroxide. This is not the case really, but may be assumed for the sake of comparing mica-slate with clay-slate, in which the iron is also assumed to be in the state of peroxide.

This diversity in the composition of mica leads to the conclusion that any sedimentary rock containing bases in proportions varying between the two extremes, as I and VI, may be converted into mica-slate. Among the varieties of clay-slate analysed by Frick, Pleischel and Sauvage,[†] the proportions of the oxygen in the bases containing three equivalents of oxygen to that in the bases containing one equivalent are:—

Goslar	4·10	Rimogne	4·40
Beindorf	6·84	Monthermé	8·66
Lehsten	6·84	Selkethal	6·00
Prague	3·24	Lüdenscheidt	15·11
Deville	5·16		

Here the extreme proportions are much the same as in the case of mica-slate, and therefore it appears possible that any one of these clay-slates might be converted into mica-slate. The average amount of silica in these clay-slates is 64 per cent., that of potash mica 47 per cent., consequently they would yield mica-slate containing on the average about 24 per cent. of quartz. However, Sauvage found in the clay-slate of Monthermé 33 per cent. of quartz, and in that of Deville 44·3 per cent. In clay-slate of this kind the silica of the silicates would be insufficient for complete conversion into mica; there would be a residue of clay-slate substance and a micaceous clay-slate would be produced.

The mica in the above varieties of mica-slate was mostly very ferruginous, not only the magnesian mica of Nos. I and II, but also that of Nos. III and IV, containing but little magnesia, and in this respect it differs from the mica in other rocks, which generally contains but little iron.

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[*] English edition, ii, 368.

[†] See ante, p. 122, et seq.

The maximum and minimum amounts of peroxide of iron in the mica-slates Nos. I to VI are reduced to 17·6 and 7·6 per cent. when they are referred to clay-slate containing 64 per cent. of silica, that is to say, such a clay-slate must have contained those amounts of peroxide of iron in order to be converted into those mica-slates. The maximum and minimum amounts of peroxide of iron in the above clay-slates are 14·67 and 4·66 per cent. The amounts of peroxide of iron in the mica-slates Nos. III to VI are within these limits, but those in Nos. I and II are greater.

The roofing slates Nos. XXI and XXII * contain, when the carbonates are deducted, more iron than any clay-slate yet analysed, consequently they might give rise to the most ferruginous kinds of mica-slate.

The maximum and minimum amounts of alumina in the mica-slates Nos. I to VI are reduced to 28·83 and 11·42 per cent. when they are referred to clay-slate containing 64 per cent. of silica. The maximum and minimum amounts of alumina in the above clay-slates are 24·3 and 14·89 per cent. The amounts of alumina in the mica-slates Nos. III to VI fall within these limits; but those in Nos. I and II are less.

Since, therefore, neither the amounts of alumina nor of peroxide of iron in these mica-slates admit of the conclusion that they were produced from clay-slate, and since none of the clay-slates contain so much magnesia as the mica-slate requires, it is not probable that mica-slate, containing magnesian mica of such composition, has originated from clay-slate, unless some kind of clay-slate should be met with that has a composition totally different from those that have hitherto been analysed.

In like manner the maximum and minimum amounts of alkalies in the mica-slates Nos. I to VI are reduced to 6·49 and 3·09 per cent. in a clay-slate containing 64 per cent. of silica. The above clay-slates mostly contain less alkalies than the mica-slates. The maximum of 7·87 per cent. in Taunus slate exceeds the amount in mica-slate; but the minimum is only 1·88 per cent. The average amount of alkalies in the mica-slates is 5·01 per cent., and that in the clay-slates is only 3·37 per cent. Since, moreover, the minimum amount of alkalies is in the magnesian mica-slate,

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* See ante, p. 130.

No. I, which cannot have originated from clay-slate, and since the amount of alkalies in the other mica-slates exceeds that in the clay-slates, excepting the Taunus slate, it is probable that most clay-slates do not contain enough alkalies to be completely convertible into mica-slate. In this case, therefore, the metamorphosis would only give rise to micaceous clay-slate.

Thus it appears, that by no means every clay-slate contains the constituents requisite for its complete conversion into mica-slate; there is generally a deficiency either of peroxide of iron or alkalies, or both. The Taunus slate contains abundance of both constituents, but it does not anywhere present indications of conversion into mica-slate, although it has to some extent a crystalline structure. It contains albite, crystallized in drusy cavities, and the quartzose slate at Würzburg contains albite as large fine-grained masses and twin crystals.* Therefore, the alteration that has taken place in the Taunus slate, especially that which has a violet colour, has not tended to the production of mica-slate, but has produced a mixture of sericite and quartz. The mineral to which List † has given this name, in consequence of its silky appearance, has a composition of such a nature, that by the elimination of a considerable portion of its silica, mica might be produced. It may, perhaps, be classed with the micaceous constituent of the slates in the Ardennes. There is some resemblance between sericite and the mica in the mica-slates Nos. IV and V, the difference consisting chiefly in the larger amount of alkalies in the sericite. By the elimination of alkaline silicate from sericite, it might be converted into mica, like that in Nos. IV and V.

Clay-slates, like those from the "Pferd" mine ‡ have a composition so closely resembling potash-mica, that they might be converted into mica-slate, containing but little quartz.

The presence in mica-slate of minerals that do not contain alkalies, such as garnet, tourmaline, andalusite, etc., shows that even clay-slate, containing but a small amount of alkalies, may be converted into mica-slate. The production of garnet, which is such a frequent constituent of mica-slate, would especially tend to increase the amount of alkalies in clay-slate. The varieties of garnet occurring in mica-slate are partly calcareous garnet, as at St. Gotthardt; ferruginous garnet, as at the Zillerthal and New

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* F. Sandberger.—Jahrb. d. Vereins für Naturkunde im Herzog. Nassau, vi, 4.

† Ibid. vi, 131.

‡ See ante, p. 127; Nos. XV and XVI.

York; partly iron and lime garnet, as in the bed of limestone in the mica-slate at Lindbobruch, in Westmannland. The above-mentioned mica-slates, Nos. III, IV, and VI, in which garnet occurs, do not contain any lime. The garnet contains some lime, but not much, as will be seen by the following analyses:—

	Red Garnet in III.	Green Garnet in IV.	Red Garnet in VI.
Silica	36·02	32·60	48·09
Alumina	18·15	8·99	19·63
Peroxide of iron	20·32	46·35	30·44
Protoxide of iron	21·98*	..	..
Sesquioxide of manganese	0·31	..	trace
Lime	2·20	2·72	1·35
Magnesia	1·02	2·87	2·86
Loss	..	6·47	2·63
	100·00	100·00	100·00

None of these garnets effervesced with acid, but boiling hydrochloric acid extracted some peroxide of iron with traces of lime and magnesia.

The sedimentary rocks, from which these three mica-slates were produced, could not have contained much lime, and this agrees with the conjecture that they were not clay-slate. The mica-slate, Nos. III and VI, and the garnet occurring in it, both contain much iron; No. IV contains little; but the garnet in this slate contains more than any other.

It is possible that even calcareous garnet may occur in mica-slate that has originated from clay-slate. In the mica-slate, No. V, calcareous garnet might have been produced.

The large amount of iron in the sedimentary rocks, from which the mica-slate and garnet, No. IV, have been produced, was, most probably, disseminated uniformly throughout the mass. It is easy to perceive that by the action of water, certain constituents of a rock may be locally accumulated, but it would be very difficult to account for this phenomenon according to the doctrine of igneous metamorphism.

The mica-slate, No. VII, cannot have originated from clay-slate, because it contains more silica than the most quartzose clay-slate. Probably quartzose grauwacke furnished the material.

The occurrence of laminæ of mica in the joints of quartz rock, the association of this rock with mica-slate, and the transition of quartz-slate into this rock and gneiss, have already been referred to.[*] Whether the laminæ of mica constitute but a very small proportion of the mass of such a rock, or whether the mica occurs as true mica-slate, both it and the quartz must have been produced in the same manner.

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* Calculated from the excess.

The analysis of the rock, No. VIII, was made in the absence of mica-slate, originating from non-fossiliferous clay-slate. The composition of the primitive clay-slate, No. XXIII,[†] certainly differs from that of this rock, but there is some resemblance between it and the green-slate at Neuhof,[‡] and the hornblende-slate at Mittel-Steine.[§] These three rocks, as well as the green-slate of Neise-Wehr,[||] may be classed together, and were characterized by containing a large amount of iron, exceeding that of alumina. This resemblance shows that from nearly the same material there may be produced either green-slate, hornblende-slate, or mica-slate, according to circumstances.

It is self-evident that water, whether that of the ocean or surface water, may, by infiltration or abstraction of constituents, change the composition of clay-slate, and bring it nearer to that of mica-slate.

By digesting powdered clay-slate with hydrochloric acid, Sauvage obtained a white residue, which, when suspended in water, appeared to consist of laminæ[¶] that reflected light, but had not the appearance of mica. This residue, from three varieties of clay-slate, had the following composition:—

	I. Deville.	II. Rimogne.	III. Monthermé.
Silica	45·91	44·59	49·60
Alumina	36·96	36·66	42 29
Protoxide of iron	6·48	5·74	..
Lime	..	1·66	1·72
Magnesia	4·89	4·31	0·68
Potash	5·76	4·74	3·56
Soda	..	2·30	2·15
	100·00	100·00	100·00
Amount in clay-slate	43·34	42·66	45·49 per ct.

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[*] English edition, ii, 469.

[†] See ante, p. 136.

[‡] See ante, p. 321.

[§] See ante, p. 322.

[||] See ante, p. 321.

[¶] See ante, p. 126.

These analyses admit of a comparison of the micaceous constituent of clay-slate with the mica of mica-slate. They correspond in being decomposed by sulphuric acid. The compositions of Nos. I and II approximate to that of the potash-mica of Utoe, Fahlun, Kimito, Ochotz, and Siberia,[*] except that there is rather less potash and more magnesia than in these varieties of mica. The composition of No. III differs from that of mica by the total absence of protoxide of iron.

The oxygen of the bases containing three equivalents of oxygen as compared with that in the bases containing one equivalent, amounts to:—

Deville.	Rimogne.	Monthermé.
6·72	5·36	10·34

These numbers are within the limits that have been given for the mica-slates.[†]

The amounts of magnesia and of alkalies also agree with those in mica-slate; but there is a considerable difference as regards alumina and peroxide of iron, the former being much more, the latter much less, than in mica-slate. If, therefore, the micaceous constituent of all kinds of clay-slate has the same composition as that in the clay-slate of the Ardennes, its conversion into mica-slate would be attended with elimination of alumina and introduction of iron. Since the loss of alumina would relatively augment the amounts of oxide of iron and other bases, the composition would in this way be brought nearer that of the mica in mica-slate. This is a simple process which, it has already been shown, actually takes place in the conversion of andalusite into mica.[‡]

The similarity of the micaceous constituents of clay-slate to the above-mentioned varieties of potash-mica that occur in granite, justifies the opinion that these constituents likewise originate from disintegrated granite, and that by the elimination of some alumina they pass into the micaceous constituent of mica-slate. But if it is only the micaceous constituent of the clay-slate that is converted into the mica of mica-slate, there would remain the green-coloured constituent of the clay-slate, amounting from 10 to 30 per cent., which is dissolved by hydrochloric acid, and in its composition resembles chlorite, especially that kind called ripidolite. In this case clay-slate, with only about 40 per cent. of mica would be produced, but not true mica-slate.

The micaceous constituent of the slate of Monthermé also occurs in the slates at Fumay and Charleville. It presents a greater resemblance to andalusite that has already taken up some alkaline silicate. Its conversion into true mica would be analogous to the conversion of andalusite into mica.

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[*] Klaproth.

[†] See ante, 346.

[‡] English edition, ii, 396.

B.—CHLORITE-SLATE.

This rock always presents very distinct stratification. The chief constituent is chlorite, sometimes accompanied by quartz or felspar, and frequently containing an admixture of mica or talc.

The only analysis of chlorite-slate that has been made is that by Varrentrapp,* of the slate at Pfisch, in the Tyrol. This consisted of—

Silica	31·54
Alumina	5·44
Peroxide of iron	10·18
Magnesia....	41·54
Water	9·32
	98·02

The composition of this rock differs from that of chlorite and ripidolite † in the small amount of alumina and the very large amount of magnesia it contains. It must, therefore, be conjectured that this slate is either a mixture of chlorite with some other mineral, perhaps talc, or that it contains a peculiar species of chlorite.

C.—TALC-SLATE.

The rock called talc-slate is often quite without magnesia, as is shown by the following analyses:—

	I.	II.	III.	IV.
Silica	48·04	50·20	40·70	57·83
Alumina	30·99	35·90	18·15	7·06
Peroxide of iron	3·74	2·36	5·25	9·45
Lime .. .. .. }	2·80	..	..	..
Magnesia .. .. .. }		..	..	25·58
Potash .. .. .. }	7·89	..	11·16	..
Soda .. .. .. }		8·45	1·23	..
Carbonate of lime	..	..	22·74	..
Water	6·54	2·45	0·60	..
	100·00	99·36	99·83	99·92

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* Poggend. Annal. xlviii. 189.

† English edition, ii, 407.

Analysed by

I. Talc-slate from Fahlun. Gahn and Berzelius.[*]

II. Talc-slate from St. Gotthardt. Schafhäutl.[†]

This slate contains both syenite and staurolite.

III. Talc-slate from the Zillerthal, in the Tyrol. Schafhäutl.[‡]

This slate contains mica, and is probably a calcareous mica-slate.

IV. Talc-slate of Hof Gastein. Wornum.[§]

If the magnesia in this slate is regarded as existing in talc it would require 47·63 per cent. of silica. The remaining 10·2 per cent. of silica, together with the alumina and peroxide of iron, would correspond with a very ferruginous clay.

CHAPTER LVII.

PHONOLITIC AND LEUCITIC ROCKS.

PHONOLITE requires attention, chiefly because there is scarcely any other rock in which the mineralogical constituents can be recognized so distinctly by chemical analysis. The difficulty of decomposing the felspathic portion of phonolite by hydrochloric acid, admits of the separation of the zeolitic portion by this means with more satisfactory results than are obtainable in the case of other rocks.[‖]

Phonolite sometimes contains small crystals of glassy felspar, but in many instances this mineral is either absent or not recognizable by the eye.[¶] The phonolite of the Rhön is very often free from hornblende, augite, magnetic oxide of iron, and mica. Zeolite and chabasite are rarely met with. It is rarely disintegrated more than a line deep. When quite decomposed it appears to have a thin schistose structure, and is easily separated into thin laminæ.* In breaking the very compact phonolite rocks round the lake of Laach, no indication of alteration can be recognized, nor yet any moisture on the surfaces of fracture. Only in one among a number of specimens tested with acid was a very slight effervescence observed near a sodalite crystal. Indeed, if it were not for the mechanical separation of this rock into very thin plates, it would very rarely be decomposed. The phonolitic rock in the neighbouring locality of Bengberg presents the same characters.

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[*] Schweigg. Journ. Bd. xvi, s. 267.

[†] Annal. d. Chemie und Pharm. Bd. xlvi, s. 334.

[‡] Ebend. s. 330.

[§] Rammelsberg, Suppl. ii, s. 145.

[‖] See ante, p. 212.

[¶] G. Rose.—Poggend. xlvii, 194.

In the Rhön district trachytic phonolite occurs, the whole mass of which presents a crystalline tendency. The felspar crystals are larger than in true phonolite, and are often traversed by wide fissures, or irregular drusy cavities, containing analcime, mesotype, calcedony, steatite, etc.† Hornblende, augite, magnetic oxide of iron, and especially mica, as well-developed crystals, are met with almost in every part of these rocks, and titanite is associated with them. In the interstices of these crystals zeolitic substances are recognizable. These rocks disintegrate, in consequence of containing easily decomposable zeolitic substances, much more rapidly and to a greater depth than the true phonolite. In the case of the felspar crystals the alteration commences at the interior, as the external crusts consist of pure felspar free from zeolites. In this way the detached fragments acquire a rounded form and blunt edges.‡

Gutberlet states that the basalt and tuff in the phonolitic district of the Rhön generally contain such a quantity of phonolite fragments that they appear like a phonolitic conglomerate with basaltic cementing material. He classes these rocks in four distinct series, and comes to the conclusion, that the older phonolite was first forced up, carrying with it the normal sedimentary rock—variegated sandstone and shelly limestone; that the older basalt penetrated the older phonolite and the more recent trachytic-phonolite, and that this again penetrated the more recent basalt.

Since the tilting of sedimentary strata may be regarded as an indication of the protrusion of crystalline rocks, it would seem that the phonolite and basalt of the Rhön district are protruded masses. But in this case, as in others, the phonolite cannot have been protruded in the same condition that it now presents, any more than other crystalline rocks; whether they were originally melted, pasty, or solid masses, the development of their constituent minerals was in all cases a subsequent act. The amount of zeolitic constituents in crystalline rocks precludes the possibility of regarding such rocks as having been produced, in their present condition, by igneous action. Phonolitic conglomerates, with basaltic cementing material, present, moreover, the characters of the conglomerates in sedimentary rocks.

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* Gutberlet.—n. Jahrb. für Min. 1845, p. 129.

† Steatite is said to occur in the phonolite of the Pferdskopf, disseminated through the entire mass. This is questionable, because phonolite rarely contains any magnesia.

‡ Gutberlet, op. cit.

	I.	II.	III.
Silica	57·70	67·98	53·70
Alumina	22·80	18·93	19·73
Peroxide of iron	4·25	2·67	3·55
Sesquioxide of manganese	..	..	1·09
Lime	1·05	0·86	1·46
Magnesia	0·55	0·49	..
Potash	3·45	5·44	7·24
Soda	9·70	3·26	7·43
Sulphuric acid	..	trace	0·12
Water	..	..	3·19
Hydrochloric acid and organic substance	..	..	trace
	99·50	99·63	97·51
O. Q.	0·518	0·335	0·335

	Analysed by
I. Phonolite from Rothenberg, near Brüx, unaltered.	Struve.[*]
II. The white disintegrated crust of this phonolite.	Struve.[†]
III. Phonolite from Hohenkrähen, in Hegau.	Gmelin.[‡]

	IV.	V.	VI.
Silica	61·88	61·90	63·68
Alumina	18·49	17·75	16·35
Peroxide of iron	3·82	3·80	5·53
Sesquioxide of manganese	0·51	0·77	0·63
Lime	1·28	0·03	1·46
Potash	3·63	8·27	9·01
Soda	6·72	6·18	4·10
Titanic acid	..	0·10	0·14
Water	1·34	0·67	0·63
	97·67	99·47	101·53
O. Q.	0·393	0·396	0·380

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[*] Poggend. Ann. vii, 348.

[†] Poggend Ann. vii, 348.

[‡] Op. cit.

Analysed by

IV. Phonolite from Pferdekuppe, on the Rhön. — Gmelin.
V. Phonolite from Abtsrode, unaltered. — Gmelin.
VI. Phonolite from Abtsrode, disintegrated. — Gmelin.

	VII.	VIII.	IX.
Silica	60·02	56·65	54·09
Alumina	21·46	16·94	24·09
Peroxide of iron	4·73	3·90	1·25
Sesquioxide of manganese	..	..	0·32
Lime	1·58	1·95	0·69
Magnesia	0·61	1·70	1·38
Potash	1·88	9·25	4·24
Soda	8·86	2·67	9·21
Oxide of copper	..	..	0·01
Water	1·49	4·99	3·28
	100·63	98·32	98·56
O. Q.	0·514	0·426	0·550

Analysed by

VII. Phonolite from Ebersberg. — E. E. Schmid.*

This rock is very schistose, homogeneous, and free from crystalline minerals.

VIII. Phonolite from Marienberg, near Aussig (Bohemia). — Meyer.†

Does not contain any visible constituents, excepting here and there small imbedded crystals of titanite, hornblende, and a few granules of magnetic oxide of iron. There is no glassy-felspar. This phonolite, like that of Bilin, is said to contain apophyllite.

IX. Phonolite from Whisterschan, near Teplitz. — Redtenbacher.‡

Contains very few crystals of glassy-felspar.

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* Poggend. Ann. lxxxix, 295.

† Ibid.

‡ Ibid. xlviii, 491.

	X.	XI.	XII.	XIII.
Silica ..	51·82	65·82	64·56	65·36
Alumina	21·05	19·58	19·41	19·41
Peroxide of iron	..	1·60	..	..
Magnetic oxide of iron	6·59	..	0·73	0·43
Sesquioxide of manganese	..	0·09	0·18	..
Lime ..	3·18	0·84	0·56	0·55
Magnesia	..	0·42	0·88	0·87
Potash	12·67	8·52	13·68	9·32
Soda ..		3·13		4·06
Water ..	4·69	..	..	..
	100·00	100·00	100·00	100·00

Analysed by

X. Phonolite from Schlossberg, near Teplitz. Prettner.*

XI. Phonolite from Kostenblatt (Bohemia). Heffter and Joy.†

In this analysis the portion decomposable by acids was separated, and the silica originating from it separated by a solution of carbonate of soda.

XII and XIII. Glassy-felspar crystals, from decomposed phonolite at Kostenblatt. } Heffter and Joy.

The last three analyses show that the felspar crystals have the same composition as that portion of the phonolite which are not decomposed by acids. From the large amount of felspathic substance in phonolite, G. Rose infers that only a small part of it can crystallize, the greater portion being intimately mixed with the zeolitic substance of the matrix.

The proportions of zeolitic and felspathic substances in the above specimens of phonolite were as follow:—

	Zeolitic.	Felspathic.
In III	55·13	44·87
IV	18·59	81·41
V	15·84	84·16
VI	4·21	95·79
VII	19·07	80·56
VIII	37·47	62·53
IX	48·97	51·03
X	29·41	70·59

In white decomposed phonolite, from the Mittelgebirge, in Bohemia, Schmorl‡ found

Zeolitic substance.		Felspathic substance.
3.13	and	96·61 containing
0·26 peroxide of iron		6·40 potash
		3·30 soda

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* Rammelsberg.—Handwörterb. ii, 42.

† Joy.—Miscel. Chem. Researches Gottingen, 1853, p. 30.

‡ Rammelsberg.—Handwörterb. i, 113.

Composition of the zeolitic portions of the above rocks.

	III A.	IV A.	V A.	VI A.
Silica	43·25	44·54	38·57	13·40
Alumina	22·90	22·14	24·32	5·66
Peroxide of iron	2·66	6·75	11·35	63·40
Sesquioxide of manganese	1·19	0·53	2·19	11·13
Lime	2·44	2·88	1·80	trace
Potash	5·45	3·06	12·66	1·07
Soda	13·67	11·38	3·08	
Sulphuric acid	0·22	..	..	..
Titanic acid	..	..	0·62	3·40
Water	5·79	7·22	4·21	..
Organic substance	..	..	0·41	..
	97·57	98·50	99·21	98·06

	VII A.	VIII A.	IX A.	X A.
Silica	56·39	43·24	41·22	42·22
Alumina	19·73	21·00	29·24	26·66
Peroxide of iron	9·82	7·82	..	9·30
Protoxide of iron	..	..	2·50	..
Sesquioxide of manganese	..	..	0·64	..
Lime	8·12	2·99	1·03	4·01
Magnesia	1·38	..	1·26	..
Potash	1·33	0·04	3·56	7·40
Soda	0·61	7·11	12·11	
Oxide of copper	..	..	0·03	..
Water	7·62	13·33	6·56	9·33
	100·00	95·53	98·15	98·92

Composition of the felspathic portions of the above rocks.

	III B.	IV B.	V B.	VI B.
Silica	66·55	65·84	66·29	66·46
Alumina	15·86	17·87	16·51	16·81
Peroxide of iron	4·63	3·16	2·39	2·99
Sesquioxide of manganese	0·98	0·51	0·99	0·17
Lime	0·27	0·34	trace	1·52
Potash	9·44	3·82	9·25	9·57
Soda	..	5·65	4·96	4·28
	97·73	97·19	100·39	101·80
O. Q.	0·312	3·341	0·333	0·347

	VII B.	VIII B.	IX B.	X B.
Silica	61·18	61·18	66·96	60·87
Alumina	21·98	19·36	18·94	15·22
Peroxide of iron	3·51	1·35	..	3·80
Lime	1·21	1·78	0·34	2·31
Magnesia	0·43	..	1·50	..
Potash	2·02	1·77	4·93	17·80
Soda	9·67	14·65	6·32	
	100·00	100·09	98·99	100·00
O. Q.	0·461	0·413	0·345	

Gmelin regards the phonolite analysed by him as mixtures of glassy-felspar and mesotype, except the first, in which the zeolitic portion contains less water than mesotype. However, the mesotype substance sometimes approximates to natrolite, sometimes mesolite or mesoline, etc. The oxygen quotient of glassy-felspar is 0·333, and it will be seen that the oxygen quotients of III B, IV B, V B, and VI B, and IX, correspond as closely with this value as could be expected. Moreover, the following experiments show, that by digesting phonolite with hydrochloric acid, the felspathic portion is so little effected that the composition cannot be sensibly altered.

Glassy-felspar, from Drachenfels, digested with hydrochloric acid, lost only 3·73 per cent., consisting chiefly of peroxide of iron, alumina, lime, and magnesia. A crystal coloured brown by oxide of iron (I), and another colourless, but containing particles of magnetic oxide of iron (II), both from Drachenfels, were repeatedly digested with hydrochloric acid, with the following results:—

Percentage of substance dissolved.

	I.	II.
After two hours..	2·06	..
„ „ „	1·43	2·02
„ „ „	0·52	1·59
„ four „	0·81	0·44
„ eight „	0·76	0·97
„ three „	0·91	0·34
„ two „	0.55	0·84
Total	7·04	6·20

The first portion consisted of—

Peroxide of iron..	1·070	1·355
Silica	0·085	
Alumina	0·200	
Lime .. Magnesia Alkalies	traces	

The second portion contained 0·068 silica; the other portions were too minute for analysis. From the diminution of the yellow colour it may be inferred that there was a smaller amount of iron in each successive portion. Probably the large amount of iron in the zeolitic portions of some of the above specimens of phonolite originated partly from admixture of magnetic oxide of iron.

According to the analyses of glassy-felspar, the proportion of alkalies is—

	Berthier.		Abich.	Schneder-man.	Mitscher-lich.	Heffter und Joy.	G. Bischof.			Schnabel.	Lasch.	Bothe.
Potash......	6·9	8·0	8·38	12·45	10·55	9·32	7·15	5·85	7·60	60·2	12·67	14·39
Soda	3·7	4·0	4·10	0·43	0·43	0·46	4·66	4·93	4·60	7·32	0·44	1·18

Except in one instance, potash preponderates. So likewise in III B, V B, VI B, potash preponderates over soda; while the contrary relation obtains in IV B, VII B, VIII B, and IX B. In the phonolite VII B and VIII B, the oxygen quotient approximates to that of oligoclase, and Schmid describes the felspathic portion of VII as being oligoclase. In both instances also the soda preponderates much over potash, as is the case with oligoclase.

In IV B, the oxygen quotient is that of glassy-felspar, but soda preponderates over potash, and since the analyses of this mineral show that, as a rule, potash preponderates over soda, the felspar in IV B and IX B cannot with certainty be regarded as glassy-felspar. The oxygen quotient of X could not be calculated, as the alkalies were not estimated separately, but to judge from the amount of silica, it is probably oligoclase. It is deserving of notice, that of the three masses of phonolite, situated near each other at Poppenhausen on the Rhön, VII contains oligoclase, while V, and probably IV, contain glassy-felspar.

G. Rose considers that the zeolitic portion of phonolite, is probably a mixture, and this appears to be indicated by the occurrence of apophylite and calc-spar, as well as natrolite, in the cavities of the phonolite at Marienberg.* Perhaps it is meant that this zeolitic portion consists of a zeolite, and an anhydrous silicate decomposable by acids, such as nephelin. This view has much in its favour. When phonolite assumes a crystalline character, sanidine always appears, zeolites more rarely. The felspathic nature of the portion that is not dissolved by acids is unmistakeably indicated by the analyses, and hence sanidine may be easily produced from it. But there is no such similarity in the composition of the zeolite portion, and it is only when dissolved by water that it can give rise to the production of definite zeolites in cavities, or more rarely in the rock matrix. The occurrence of hauyn in the phonolite of Puy-de-Dome and Cantal, as well as the small portions of sulphuric acid in several of those above referred to, render it probable that this mineral, decomposable by acids, is often mixed with the zeolitic portion.

Decomposition.—The comparison of the analyses I with II, and V with VI, shows that in the alteration of phonolite, silica and potash increase, while alumina and soda decrease. Since in the zeolitic portion of the decomposed phonolite V, the silica and potash are less, while the alumina and soda are greater than in the felspathic portions, since, moreover, the zeolitic portion amounts to 15·84 in V, and to only 4·21 per cent. in VI, the alteration of the rock may have consisted in a partial extraction of the zeolitic portion. In that case, the mass of the rock would have been reduced to the amount of 11·63 per cent., and either reduced in volume, or rendered porous in proportion.† Since zeolites may be converted into felspar,‡ the decomposition of phonolite may be regarded as a combined conversion of this kind, and partial separation of the zeolitic substance. In this case, the relative increase of silica and potash would be the result of an absolute diminution of alumina and soda, which would account for the considerable increase of iron and manganese, as well as of titanic acid, which appears in comparing the zeolitic portions VI A and V A. These oxides resist removal by water, while other constituents, and even silica, are removed in considerable amount.

Since the oxygen quotient of II is that of sanidine, this decomposed phonolite may be regarded as almost entirely felspathic, the zeolitic portion having been entirely decomposed, and for the most part removed. The decrease of soda in both I and II agrees with the preponderance of carbonate of soda over carbonate of potash in the water of springs, and also with the occurrence of zeolites, containing soda, in drusy cavities of these rocks. The phonolite IX also shows a relative diminution of the zeolitic portion, so that this appears to be a constant effect of the decomposition of phonolite.

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* The amygdaloid phonolite of Aussey is said to be rich in chabasite.—Gutberlet, op. cit.

† According to Breithaupt—Poggend. Ann. viii, 90—the density of phonolite decreases as decomposition advances; that of the fresh rock being 2·585, that of the somewhat altered rock 2·487.

‡ English edition, ii, 141 and 147.

The very unequal amount of zeolitic substance in phonolite appears to indicate that the decomposition is in different stages. It is not probable that the phonolite III, with 55·13 per cent. zeolitic substance, is still in its original condition, for when a rock is liable to decomposition, it may be supposed to have gone on since a time nearly as remote as the production of the rock. The opinion that a rock should exist unaltered for a long period, and then suddenly undergo alteration, would at least be very illogical. The permeability of rocks, and their liability to alteration, are inseparable, and it is only a perfectly impervious rock that would have a permanent existence. If such a rock existed there would not be any reason why its impermeability should ever be altered. The phonolite III is, like all other rocks, permeable by water, and consequently liable to the same alteration that is indicated by the analyses of other phonolitic rocks, and in some instances is evident from their appearance. The age of this rock cannot be determined, but it is certainly so great that it must have undergone some alteration. If this alteration consisted in a progressive conversion of the zeolitic portion into felspathic substance, accompanied by elimination of those constituents that did not enter into the composition of the latter, then the amount of zeolitic substance at some previous period must have been greater than it is at present.

So long as the production of zeolites at high temperatures has not been effected in such a manner as can be supposed to take place in rocks, it is impossible to do otherwise than regard, not only the zeolites in drusy cavities, but also those zeolitic masses that occur as constituents of rocks, as having been produced in the wet way. The former are, in fact, deposits from water,* the latter have been produced either directly or by the alteration of other minerals. However, the possibility that these minerals were of eruptive or even igneous origin, is not thereby excluded.

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* Besides the above-named zeolites occurring in drusy cavities of phonolite, natrolite also occurs in fissures, veins, and small dykes, in the phonolite of Hohenkrähen, Hohentwiel, Magdeberg, Oberschaffhausen, Aussig, Mariaschein, Schima, Fuchsberg near Salesel, Marienberg, and the Kaiserstuhl.

Pseudomorphic changes often commence with hydration,* and hydrated pseudomorphs are by far the most numerous, so that it is possible that anhydrous minerals may be converted into zeolites. Up to the present time, indeed, there is only one such case known —the conversion of nephelin into natrolite—soda mesotype†—but this case is very characteristic, because the zeolitic substance of phonolite is analogous to this zeolite. The analyses of elæolite by Scheerer elucidate this alteration.‡

Moreover, since zeolites are capable of being converted into other zeolites,§ and since pseudomorphous prehnite occurs with the form of laumontite,|| such alterations have, in all probability, taken place in the zeolitic substance of phonolite, so that it can scarcely be regarded as corresponding to any particular species of zeolite, but is more likely a mixture of several. The formation of individual minerals appears to take place only in cavities, fissures, and dykes, into which the hydrated silicates are conveyed by water.

On the other hand, since laumontite, analcime, leonhardite, and natrolite, are capable of being converted into prehnite, and since this mineral is capable of conversion into felspar, it is, from a chemical point of view, possible that other zeolites, resembling in composition those above named, may be converted, either directly or indirectly, into felspar. Like them, leonhardite, stilbite, heulandite, and edingtonite, are double silicates of alumina and lime. Analcime is a silicate of alumina and soda, and as the former, like this, are capable of conversion into felspar, it is probable that faujasite, epistilbite, chabasite, mesotype, and thomsonite, containing silicates of lime and soda, as well as phillipsite, which contains silicate of potash, may be all capable of such alteration. Moreover, when it is remembered that all these zeolites contain silicate of alumina in common with felspar, and that their other silicates are so easily decomposed by carbonate of potash, while they are almost entirely free from iron, the probability of the conversion of zeolites into felspar becomes still greater.

It is very important to have ascertained the possibility of the conversion of zeolitic substances into felspar, either in drusy cavities or in rocks. Such a rock as phonolite, with regard to which it is certain that the alteration it presents in its decomposed surface consists in the gradual diminution of its zeolitic constituent, may formerly have consisted entirely of hydrated minerals, from the alteration of which felspar has since originated. If this

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[*] English edition, i, 37.

[†] Blum.—Nachtrag, etc. ii, 132.

[‡] English edition, ii, 145.

[§] English edition, ii, 151.

[||] Ibid., ii, 149.

change, which is so clearly recognizable in the phonolite of Rothenberg (II), were to progress continuously, this rock would at some future time consist entirely of felspar.

The above remarks as to phonolite are also applicable to other rocks containing zeolitic constituents, such as basalt, dolerite, etc. In these, also, the felspathic constituent may be a product of the alteration of zeolitic substance. Just in like manner as mesolite may be regarded as having originated from labradorite by hydration, so, on the contrary, labradorite may be regarded as having originated from mesolite by the separation of water.

It is in vain, therefore, that we seek to ascertain which are original minerals or rocks; in vain that we seek to ascertain the beginning and end of the series of alterations in rocks; and the distinction between primary and secondary minerals, to which I still adhered but recently, disappears more and more as investigation progresses.

LEUCITIC ROCKS.

In the following analyses of leucitic rocks, A represents the portion decomposed by hydrochloric acid, B that not decomposed, and C the composition of the rock as a whole. The numbers in brackets indicate the relative proportion of the two.

	I A.	I B.	I C.	II C.
	(91·73)	(8·27)		
Silica	49·07	50·90	49·21	52·08
Alumina	16·71	5·37	15·76	17·30
Protoxide of iron	12·36	6·25	11·84	6·52
Lime	5·54	22·96	6·97	12·23
Magnesia	5·26	14·43	6·01	1·25
Potash	4·37	..	4·37	9·63 [*]
Soda	6·06	..	6·06	..
Loss by ignition	..	..	..	0·91
	99·37	99·91	100·22	99·92
O. Q.	0·646	0·603	0·649	0·539

I. Lava from one of the small streams at Vesuvius, that flowed early in the year 1834.

The composition of No. I B was calculated from the analysis of augite from Vesuvius by Kudernatsch.[†] This lava contains a great number of vitreous leucite crystals[‡] imbedded in the greenish-grey matrix.

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[*] Estimated as deficiency.

[†] English edition, ii, 312, No. xxviii.

[‡] Ibid, ii, 219, No. vi.

II. Rock at Monte delle Cortinelle at Roccamonfina.

This rock is characterized by containing large crystals of leucite. It almost always contains augite, sometimes mixed with felspar, apparently oligoclase or andesin. It is probable that this rock, which resembles Vesuvian lava, contains leucitic substance.

Both analyses are by Abich.* According to his calculation, the former rock contains—

Vitreous leucite	60·19	99·98
Calcareous augite	20·44	
Olivine	10·42	
Magnetic oxide of iron	8·93	

The almost complete decomposition of this lava by acids distinguishes it from all other varieties of lava. The circumstance that a part of the augite is decomposed by acids appears to be due to the decomposed state of the lava, and to the more easy decomposition of the augitic matrix than of crystalline augite, by acids.

	III A.	III B.	III C.
	(72·37)	(27·63)	
Silica	53·10	51·40	52·63
Alumina	16·58	10·20	14·82
Protoxide of iron	10·70	6·75	9·61
Lime	3·34	15·22	6·63
Magnesia	1·16	2·10	1·42
Potash	2·23	5·80	3·21
Soda	9·46	6·45	8·63
	96·57	97·92	96·95

	IV A.	IV B.	IV C.	V A.
	About (80·00)	About (20·00)	..	(51·12)
Silica	50·55	54·20	51·28	49·10
Alumina	20·30	11·45	18·53	22·28
Protoxide of iron	9·24	5·25	8·44	7·86
Lime	5·20	10·75	6·31	3·88
Magnesia	1·21	2·40	1·45	2·92
Potash	2·52	7·29	3·48	3·60
Soda	8·42	6·55	8·05	9·04
	97·44	97·89	97·54	98·68

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* Geol. Beob., p. 125.

	VI A.	VII A.	VII B.	VII C.
	(80·00)	About (75·00)	About (25·00)	
Silica	50·98	51·75	53·20	52·06
Alumina	22·04	19·62	12·63	17·88
Protoxide of iron	9·01	6·94	3·63	6·12
Lime	5·94	4·62	12·36	6·56
Magnesia	1·23	1·75	2·20	1·86
Potash	3·54	2·70	6·72	3·71
Soda	8·12	10·25	7·15	9·48
	100·86	103·63	97·89	97·67

	Analysed by
III. Lava from a crater at Vesuvius.	Dufrenoy.[*]
IV. „ „ of the year 1834.	
V. Lava from the cave at Granatello.	
VI. Lava from la Scala.	
VII. Volcanic ash, collected in 1822 at Naples.	

Rammelsberg[†] remarks, that it is striking that the portions not decomposed by acids are in all instances very rich in alkalies. Hence it might be inferred that these lavas contain a felspathic constituent that is not decomposed by acids.[‡] If the iron is deducted under the assumption that it represents magnetic oxide of iron, we should have the following oxygen ratio:—

	RO.	Alumina.	Silica.
In Nos. I, III – VII A =	3	6	18
In leucite it is =	2	6	16
Residue = augite	1	0	2

Consequently A may be regarded as a mixture of two equivalents of leucite, containing a preponderance of soda, with one equivalent of augitic substance.

The oxygen ratio in—

	RO.	Alumina.	Silica.
III B = ...	6	3	18
In leucite it is	1	3	8
Residue = augite	5	0	10

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[*] Annal. des Mines, xiii, 565.

[†] Supplt. iv, 129.

[‡] Perhaps the striking differences between Abich's and Dufrenoy's analyses, as regards the portions decomposed by acids, may be due to the length of time the digestion was continued.

		RO.	Alumina.	Silica.
In IV B and VII B	=	9	6	30
In leucite	=	2	6	16
Residue = augite	....	7	0	14

Consequently, III B is to be regarded as a mixture of leucite with five equivalents of augitic substance; IV B and VII B are to be regarded as mixtures of two equivalents of leucite with seven equivalents of augitic substance. Therefore it may be readily understood that these lavas may give rise to the production of leucite, augite, and magnetic oxide of iron.

It follows, from the comparison of these analyses, that these lavas present a tolerably close resemblance. However, it is remarkable that Nos. I and IV, though lavas from the same eruption, differ so much, especially as regards the amount of magnesia. The close correspondence of the volcanic ash No. VII C, and the lavas No. III C and IV C, is also remarkable. This would seem to indicate that the ash is nothing more than finely-divided lava. It was probably thrown out in this state by water vapour, so that it cooled rapidly, as if poured into water.

It might be expected that lava which, like No. I C from Vesuvius, contains 60·19 per cent. of vitreous leucite, would be very difficult to melt. But this does not agree with approximative determinations of its temperature. In the lava that destroyed the town of Torre del Greco in 1794, gold and copper coins have been found unmelted, silver coins melted, and some copper coins run together.* In 1819 Sir H. Davy found that a copper wire one-twentieth of an inch thick, and a silver wire one-thirtieth of an inch thick, were immediately melted when placed in the lava at Vesuvius near its source. An iron rod one-fifth of an inch thick, and an iron wire one-thirtieth of an inch thick, were not melted when held in the lava for five minutes. Consequently, the lava had in both instances about the temperature of melting copper, which is much below the melting point of leucite. There is, perhaps, no doubt that the lava of 1819, like that of 1822, was leucitic; and the analyses, Nos. I to VII, of different lavas from Vesuvius, show that they have all a tolerably uniform composition; consequently, they would all be equally fusible. The easy fusibility of these lavas is doubtless due to the considerable amounts of iron and lime they contain.

When the leucitic substance of these lavas comes to be crystallized, it might be expected that when exposed to the same heat the leucite would not be melted, but only the matrix.

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* Thompson—Gilbert's Ann. v, 436.

† Annal. de Chemie et Phys., xxxviii, 138.

The great preponderance of soda in the lava of Vesuvius renders it improbable that leucite without soda would ever be crystallized from them. But the analyses No. V, VI, X, and XI,* show how variable the relative proportions of soda and potash are in the leucite of Vesuvius. The difference in the relative proportions of these alkalies in the small leucite crystals from the leucite rock at Rieden,† admits of the conjecture that the crystals thrown out of Vesuvius may also contain unequal proportions of the alkalies.

So long as leucite was regarded as a mineral containing only potash, leucitic lava and leucitic rocks appeared to be anomalous. But since soda has been detected in the leucite, they present an analogy to the basaltic lava, for both contain augitic substance, associated in the one case with felspathic substance containing a preponderance of potash; in the other case, with felspathic substance, containing a preponderance of soda and lime.

The leucitic rock of Rieden has hitherto been found only as large blocks, and very often imbedded in the tuff, as at Nudendahl, at the Haardt, the Selberg, and on the heights of Weibern.

It is worth mentioning that in this leucitic rock, glassy-felspar is associated in small amount with the leucite, for in that mineral, also, potash preponderates over soda. There are, also, some phonolite cones in the neighbourhood, which contain glassy-felspar as the preponderating constituent.

The above-mentioned masses of tuff also contain, besides the leucitic rock, large blocks of augitic lava, phonolite, and clay-slate. At one place on the road from Nudendahl to Rieden there is a bank of phonolite thirteen feet thick, and under it a bed of tufaceous limestone, or leucitic-lava tuff, fourteen feet thick, and containing fragments of phonolite similar to that above, and sometimes passing into the mass they are imbedded in. The undermost bed is upwards of fifteen feet thick, and consists of leucitic tuff or tufaceous limestone. Near Kemfenich and Engeln there are considerable masses of phonolitic and leucitic rocks, closely resembling tufaceous limestone. The Schillköpfchen consists chiefly of phonolite or leucitic rock, with tufaceous limestone at the eastern side. The Englerkopf consists of leucitic porphyry, with opaque crystals of leucite. The fragments of augitic lava imbedded in this rock show that the leucitic porphyry is more recent than the augitic lava. The rock on the Lehrberg, containing nosean and some mica,* is similar to this rock.

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* English edition, ii, 219.

† Ibid, ii, 220, Nos. viii and ix.

All these circumstances show that there is a close connection between leucitic and phonolitic rocks. The transition of these rocks into tuff or tufaceous limestone, and the occurrence of weathered leucite crystals in the former, render it very probable that the tufaceous masses have been produced on the spot by the alteration of leucitic or phonolitic rocks. If this is the case, it may be that the rock near Bell, containing such an abundance of small leucite crystals, has originated in the same way.

If the leucitic tuff was originally leucitic porphyry, it remains to be determined whether that rock was protruded or flowed from a crater. There is nothing to indicate that it has originated like lava, and most probably it was produced before volcanic craters were formed.

The difference between the lava of Vesuvius and that of Ætna is due chiefly to the preponderance of alkalies in the one, having given rise to the production of leucite, while the preponderance of lime in the other gave rise to the production of labradorite.

CHAPTER LVIII.

TRACHYTIC ROCKS.

THESE rocks are among those that have the most simple composition; they are essentially felspathic rocks. In most varieties glassy felspar is the preponderating constituent. Abich† inferred from his analysis of the matrix of the trachyte at Drachenfels, that it contains a felspar having the crystalline form of albite, but differing from the normal composition of that mineral in containing a large amount of potash, but v. Dechen‡ questions this opinion. G. Rose, on the other hand, found in the sound portions of this trachyte, very distinct crystals of oligoclase.

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* Archiv., xxii, 589.

† Geol. Beobachtungen, üb. die vulkan. Erscheinungen etc., in Italien, 1841, p. 29.

‡ Geognost. Beschreib. des Siebengebirges.—Verhandl. des Naturhist. Vereins der preuss. Rheinlande, etc., ix, 289.

In the following analyses, with the exception of XIV and XV, soda preponderates over potash, so that if the corresponding rocks contain in their matrices, definite felspathic substance, this cannot consist merely of glassy felspar, but must also contain a felspar with a larger amount of soda. Whether this is oligoclase or albite is uncertain. Since true trachytic rocks gradually assume a doleritic character, in consequence of the introduction of lime, and the increase in the amount of soda, this change must be accompanied by increase in the amount of soda-felspar, and, in fact, the trachyte of this kind contains crystals of oligoclase. From this it might be inferred that there had been also an increase in the proportion of this felspar. It would be desirable to classify trachytic rocks, according to their composition, in a series, with those containing most potash, at one end, and, at the other, those containing most soda, lime, and magnesia. The former would comprise the rocks containing most glassy felspar, the latter those containing most oligoclase or other soda-felspar. To do this, the relative proportion of the alkalies must be carefully estimated.

In some varieties of trachytic rocks, labradorite occurs in the place of the soda-felspar; and this is not remarkable, because of the doleritic character of these rocks.

Among the accessory constituents of trachytic rocks, hornblende is very frequently met with in small amount, black mica* more rarely, and magnetic oxide of iron almost always. Most trachytic rocks contain a small amount of water,† and those that are decomposed contain a large amount.

The presence of quartz is recognizable in most kinds of trachytic rocks, either as nests, veins, or granules. When the analyses of trachytic rocks indicate more silica than the most siliceous species of felspar, or more than 70 per cent., there can be no doubt as to the presence of quartz. Those which contain less silica may also contain quartz. In trachyte containing labradorite, quartz was recognizable, though the amount of silica was only 58 per cent.

Other accessory constituents are titanite, specular oxide of iron, garnet, olivine, nephelin, augite, and iron pyrites. The cavities contain calc-spar, chabasite, and mesotype.

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* The trachyte of Monte Sta. Croce, in Roccamonfina, contains a large quantity of copper-coloured mica. Pilla.—n. Jahrb. 1845, p. 846. This earthy trachyte contains decomposed felspar, and the mica may have originated from the felspar.

† Durocher.—Comptes Rendus, xxiv, 209.

Trachytic conglomerates, trachytic porphyry, pearlstone, pitchstone, obsidian pumicestone, and trachytic tuff, are either varieties of, or closely related to, trachytic rocks.

A.—*Trachytic Rocks of the Siebengebirge and the Eifel.*

	I.	II.	II A.	II B.
Silica	72·26	67·09	70·22	46·11
Alumina	13·77	15·63	17·29	4·58
Peroxide of iron	2·72	4·59	0·82	29·88
Titanic acid (ferruginous) ..	..	0·38	..	2·95
Sesquioxide of manganese ..	trace	..	..	1·22
Lime	0·22	2·25	2·09	3·33
Magnesia	0·20	0·97	0·41	4·66
Potash	4·32	3·56	3·71	1·58
Soda	6·56	5·07	5·62	1·47
Loss by ignition	0·46	0·45	..	2·96
	100·51	99·99	100·16	98·74
O. Q.	0·261	0·333	0·329	0·651
Density	2·631* 2·657†	2·689‡	..	..

I. Trachyte of Berkum.

The fine-grained white matrix of this rock contains throughout small particles of hornblende, and perhaps also of magnetic oxide of iron and glassy felspar. In powdering the rock, it was found to contain a great number of ochre yellow fragments, probably the residue of decomposed hornblende or magnetic oxide of iron. It did not give off any water at 212° F. It certainly contains free silica, though quartz was not recognizable in it. A steatitic substance in the fissures of this rock consisted of—

Silica	47·99	97·97
Alumina, containing some iron ..	37·85	
Magnesia	0·31	
Loss by ignition	11·82	

II. Matrix of the Drachenfels trachyte.

This rock consists of a fine-grained greyish-white felspathic mass, with numerous imbedded crystals of glassy felspar. The interstices between the fragments of broken crystals contain quartz crystals, and sometimes the ordinary matrix in which hornblende crystals are recognizable, as well as mica and magnetic oxide of iron.

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* From the old quarry. † From the Dom quarry.
‡ Without glassy felspar.

At the foot of the Drachenfels there is a quarry presenting very remarkable fissures filled with a pink mineral containing—

	G. Bischof.	Schnabel.
Silica	64·54	56·77
Alumina	6·04	15·77
Peroxide of iron	4·56	1·65
Sesquioxide of manganese ..	4·61	0·86
Lime	3·96	2·76
Magnesia	0·41	1·30
Water and organic substance ..	11·33	17·11
Alkalies	4·55	3·78
	100·00	100·00

In the trachytic conglomerate below the Drachenfels, psilomelan occurs as a vein three or four inches thick.*

Analysed by

II A. The portion not decomposed by hydrochloric acid. } Abich.

II B. The portion decomposed by hydrochloric acid amounting to 12·51 per cent. according to Abich, and, according to Varrentrapp, to 8·98 per cent.

The peroxide of iron in II and II A was considered to be in the state of magnetic oxide of iron.

	III.	IV.	V.	VI.
Silica	64·21	62·11	62·38	57·46
Alumina	16·98	19·45	16·88	17·84
Peroxide of iron	6·69	5·02	7·33	6·50
Sesquioxide of manganese ..	..	1·15	trace	..
Lime	0·49	1·29	3·49	2·72
Magnesia	0·18	0·29	0·82	0·72
Potash	4·41	3·98	2·94	4·18
Soda	5·13	6·01	4·42	4·43
Loss by ignition	1·00	..	0·87	..
Water	..	..	..	3·90
	99·09	99·30	99·13	97·75
O. Q.	0·365	0·449	0·400	0·441
Density	2·781	..	..	..

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* v. Huene.—Zeitschr. d. deutsch. geol. Ges. iv, 576. A similar instance of the occurrence of psilomelan was observed by Guthberlet in the trachytic porphyry of the Rhön. Ibid. v, 603.

III. Trachyte at the Kühlsbrunnen.

Fine-grained grey matrix, separable more easily in one direction than in others. At the surface of fracture there are sometimes greyish-yellow patches of felspar. The rock contains numerous crystals of hornblende, and some magnetic oxide of iron.

Analysed by

IV. The same trachyte, where it is not sound and presents ochrey patches. } Bothe.*

V. Trachyte of the Wolkenburg.

The fine-grained matrix is at some parts blueish-grey, and at the exterior of the columnar masses yellowish-grey, reddish, and sometimes greenish.

There are a number of hornblende crystals imbedded, and very few laminæ of mica. The rock contains much magnetic oxide of iron, and effervesces throughout with acid, principally where there are cracks, and calc-spar occurs not only in cavities † but also imbedded in the matrix. The reddish coloured trachyte at the summit of the Wolkenburg does not effervesce with acids.

The different colours of the rock indicate decomposition. The carbonate of lime originates from an easily decomposable silicate. This is more probably labradorite, since the trachytic rock No. XXVIII really contains this felspar. The composition of the Wolkenburg trachyte has also some resemblance to that of decomposed labradorite.‡

In the rocks Nos. I to V soda preponderates over potash, and in those following, the opposite relation prevails. Consequently, the mass of these rocks must contain, besides glassy felspar, some other species such as albite or oligoclase, in which soda preponderates. The latter is present as crystals, in the trachyte No. II, and the crystalline mineral in the trachyte at Röttchen contains, according to Bothe,

Silica	63·16
Alumina	22·14
Peroxide of iron	2·51
Lime	2·07
Magnesia	0·65
Potash	1·34
Soda	8·13

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* v. Dechen.—Op. cit. 340.

† Nose.—Beitr. zu den Vorstellungsarten über vulk. Gegenstände, 1792, p. 443, states that most of the calc-spar druses are surrounded with a crust containing more hornblende and mica than the rest of the rock.

‡ English edition, ii, p. 209. No. IX A.

This is undoubtedly oligoclase, and consequently its presence in the matrix of the rock is probable. The proportion of soda to potash, in the portion II A, that is not decomposed by acids, induced Abich to infer the presence of albite containing a considerable amount of potash. But even albite with a small amount of potash would, when mixed with glassy felspar, give a rock in which the relative proportion of alkalies would be similar to that of No. II. The presence of 70·22 per cent. silica in II A, agrees with this view, since it does not much exceed the amount in albite and glassy felspar, and the excess is probably due to the presence of quartz. The amount of lime in II A also agrees with this view, since this earth is present even in larger amount in some kinds of glassy felspar, and since most varieties of albite also contain some lime.

Therefore the only conclusion to be drawn is, that the matrices of the trachytes Nos. I to V contain glassy felspar mixed with either oligoclase or albite. The presence of glassy felspar in the matrix is probable, because, in most instances, the mass of a rock contains the same minerals in an amorphous condition as occur imbedded in it as crystals.

VI. Trachyte at the Selberg, near Quiddelbach, between Adenau and Kelberg, in the Eifel.

This rock gave off much water at 212° F.; after ignition it was pale brown, it effervesced copiously with acids, and contained some magnetic oxide of iron. The considerable loss by ignition agrees with the circumstance, that the silica and other constituents separated in the analysis were almost black. Acetic acid extracted from this trachyte 1·37 per cent. carbonate of lime, 0·58 alumina, and 1·24 peroxide of iron. The residue decomposed by carbonate of soda contained 55·6 silica, 2·05 lime, and 0·77 magnesia. The lime of the carbonate and silicate amounted to 2·82, or nearly as much as in the analysis No. VI. This trachyte likewise seems to contain labradorite like the previous one.

The other specimens of trachyte examined by me, were not subjected to a separate analysis, but there can be no doubt that they contained portions soluble and insoluble in acids.

Analyses of Trachytic Conglomerate in the Siebengebirge.

	VII.	VIII.	VIII A.	VIII B.
Silica	62·83	66·39	71·80	49·23
Alumina	21·55	17·74	18·75	17·63
Peroxide of iron	4·11	4·97	3 77	20·18
Lime	0·72	0·53	0·12	5·02
Magnesia	0·42	0·47	0·17	3·90
Potash	3·35	3·05	3·29	2·26
Soda	3·02	1·94	2·07	1·76
Water	4·19	4·89	..	..
	100·19	99·98	99·97	99·93

VII. Trachytic conglomerate of the Ofenkuhlen.

This rock is quite homogeneous, white, and thinly stratified.

VIII. The same rock, analysed by von der Marck.*

It was partly decomposed by digestion with hydrochloric acid, and gave—

	G. Bischof after 24 hours' digestion.	Schnabel.†	v. d. Marck.
Decomposable portion	15·96	23·92	13·25
Undecomposable portion	84·04	76·08	86·75

VIII A. Decomposable portion of No. VIII.

VIII B. Undecomposable portion of No. VIII.

Comparing Nos. IV and III, there seems to be an augmentation of alumina, and a diminution of silica in consequence of decomposition. A still greater increase of alumina is apparent when No. VIII is compared with trachyte. If trachyte, such as No. IV, yielded the material for this conglomerate, there would have been only 6 per cent. silica, and 5 per cent. alkalies removed from it, or nearly mono-silicate of soda, while the silicate of potash remained for the most part.

Opal-jasper occurs as veins and nodules in the trachytic conglomerate, showing that elimination of silica took place after the deposition of the mass. It may be that the cementing material may have the same origin.

* v. Dechen.—Op. cit. p. 451.

† Ibid. Schnabel found 4·99 per cent. of water, and small quantities of chlorine, sulphuric, and phosphoric acid.

	IX.	IX A.	IX B.	IX C.
Silica	78·87	78·64	67·90	66·33
Alumina	11·62	11·59	19·25	19 02
Peroxide of iron	1·12	1·05	1·42	0·52
Lime	0·54	0·36	..	0 76
Magnesia	0·46	0·26	0·64	..
Potash	3·11	7·05	5·35	6·02
Soda	3·94		4·93	7·32
Loss by ignition	1·00	0·56	..	..
	100·66	99·51	99·49	99·97
O. Q.	0·184	..	0·337	0·352
Density	2·475	..	..	..

IX. Pecular rock at the Lesser Rosenau.

This rock contains a few small translucent crystals of felspar; at some places it is transversed by veins of blueish quartz-like calcedony, and sometimes fragments of another rock are imbedded in it.

IX A. The same rock after separating the crystals of felspar.

IX B. Felspar crystals from the same rock.

These crystals were quite sound and did not contain any water.

IX C. Glassy felspar crystals from the trachytic conglomerate at the Langenberg.

The glassy felspar in trachytic rocks always contains potash in larger amount than soda.*

Nöggerath† is of opinion that the greater part of the fragments of trachyte in trachytic conglomerate have been derived from the adjoining mountains. L. Horner‡ states that these fragments often differ from all of the varieties of trachyte constituting mountains, and Zehler § adopts the same opinion. However, v. Dechen || states that this is not the case as regards the trachytic conglomerate of the Siebengebirge.

It is probable that the differences observed between the trachyte fragments in conglomerate and that constituting mountains, is due to alteration that has taken place. Thus, the trachyte of the Bolvershahn is so liable to decomposition, that the fragments crumble down and yield a mass similar to the conglomerate.

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* English edition, ii, p. 188.

† Rheinland-Westphalen, i, 129.

‡ Trans. of the Geol. Soc. (2) iv, 442, 467.

§ Das Siebengebirge und seine Umgebungen, 1837.

|| Op. cit. p. 455.

Since the trachytic conglomerates are invariably more recent than the brown coal and the clay and sandstone associated with them, v. Dechen regards them as belonging to the brown coal measures. The idea of an eruptive origin, such as that suggested by Horner, cannot be entertained.

The glassy felspar crystals in this conglomerate are often very sound and unaltered, but this could not be the case if they had existed in the trachyte from which these masses of conglomerate originated, for trachyte never contains such well-developed crystals. The very distinct stratification of trachytic conglomerate, as well as the occurrence in it of fossil wood and impressions of leaves, are sufficient evidence of its sedimentary origin. Crystals of glassy felspar would not, however, have borne transport by water without being rounded as the fragments of grauwacke are. Consequently, we must infer that these crystals have been produced in the wet way, subsequent to the deposition of the conglomerate, and that the large crystals occurring in some trachyte dykes in the conglomerate have originated in the same manner, whatever may have been the origin of these dykes.

B.—*Trachyte in Hungary and Styria.*

These trachytic rocks are situated at the northern boundary of the Hungarian plains, and at the south of the Carpathians, constituting five isolated groups without either craters or lava streams.

	X.	XI.	XII.	XIII.
Silica	58·11	53·85	58·49	57·17
Alumina	17·26	17 95	17·86	16·90
Protoxide of iron	5·72	6·94	6·45	8·50
Sesquioxide of manganese	..	..	..	trace
Lime	10·85	8·33	6·96	6·30
Magnesia	1·81	6·47	2·60	1·90
Potash	3·66	1·34	2·82	3·90
Soda	4·01	1·91	1·86	1·00
Water	1·23	2·55	2·47	3·38
Carbonic acid	0·33	0·44	0·22	..
	102·98	99·78	99·73	99·05
O. Q.	0·490	0·556	0·452	0·445
Density	..	..	..	2·64

Analysed by

X. Trachyte of Srezawnica. A. Streng.*

This rock is called granitic trachyte by Beudant. The matrix is white, coarse-grained, and very hard. The imbedded crystals are very numerous, and consist of glassy felspar, with a vitreous or fatty lustre, and hornblende.

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* Poggend. Annal. xc, 103.

Analysed by

XI. Trachyte at the Hrad mountain, near Banow. } A. Streng.[*]

The matrix is fine-grained, grey, rather porous, and very hard. There are a few very small laminæ of felspar and hornblende crystals imbedded in it.

This and the previous rock effervesced copiously with acids.

XII. Reddish hard trachyte at Wissegrad, near Gran. } A. Streng.[*]

This rock contains a small quantity of crystals, mica, and quartz granules. At some parts there are druses of calc-spar.

XIII. Trachyte of Gleichenberg, in Styria. Morlot.[†]

This rock resembles felstone porphyry, is compact, and of a greyish-green colour, with a few felspar crystals.

It is difficult to form an opinion as to the composition of this rock. The small amount of silica, and the large amount of lime, might lead to the conclusion that it contains labradorite, but the proportion of soda to potash does not agree with this view.

The trachyte No. XII, is described by v. Fridau[‡] as constituting the central portion of a basaltic district of much greater extent; and it passes into a basaltic rock. Fridau also analysed a product of decomposition occurring in the trachyte of Gleichenberg.[§] It was yellowish grey, and resembled many varieties of semi-opal. A gives the composition of this substance, and B that of an argillaceous rock adjoining.

	A.	B.
Silica	50·70	89·30
Alumina	19·06	3·11
Peroxide of iron	1·13	4·83
Lime	0·56	0·14
Magnesia	0·41	0·13
Potash	3·98	..
Sulphuric acid	16·51	..
Sulphate of potash	0·31	..
„ magnesia	0·09	..
Water	7·23	3·32
	99·99	100·83

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[*] Poggend. Annal. xc, 103.

[†] Haidinger's Berichte, ii, 236, 336.

[‡] n. Jahrb. für Mineral, etc., 1849, p. 576.

[§] Ann. der Chem. u. Pharm. lxxvi, 106.

These rocks are probably products of the decomposition of trachyte by sulphuretted hydrogen. The large amount of water in the Gleichenberg trachyte, and the preponderance of potash over soda are indicative of alteration.

The trachytic rocks in the Cordilleras of Venezuela, are decomposed by water containing sulphuric acid, in the same manner as the trachyte of Gleichenberg. The streams of mud produced give rise to a true trachytic conglomerate.*

C.—*Trachytic Lava of Ischia, Monte Nuovo, and the Campi Flegræi.*

Trachytic lava occurs only in these localities.

	XIV.	XV.	XV A.	XV B.
Silica	63·04	61·03	65·00	41·68
Alumina	19·58	17·21	18·64	10·71
Peroxide of iron	5·26	4·84	0·83	23·13
Sesquioxide of manganese	..	0·17	0·13	0·83
Lime	1·57	1·43	1·23	2·32
Magnesia	0·08	2·07	1·03	6·83
Potash	5·68	7·16	9·12	1·59
Soda	4·11	4·64	3·49	9·89
Water and chlorine	0·71	0·56	..	3·14
	100·03	99·11	99·47	100·12
O. Q.	0·403	0·417	0·373	0·827
Density	..	2·641	2·631	..

Portion of XV A not decomposed by acid	82·02
And of XV B decomposed by acid	17·98
	100·00

XIV. Matrix of the lava at St. Vico between Lacco and Foria.

The glassy felspar crystals, No. VII,† were from this lava. It did not effervesce with acids, but contained some carbonaceous substance. The dark grey fine-grained matrix contains large crystals of glassy felspar, a few laminæ of mica, and some distinct acicular crystals of augite.

This lava stream is very thick, and is intersected by a very remarkable valley, the sides of which are a hundred feet high.‡

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* Acosta.—Bull. Géol. (2) viii, 489.

† Fr. Hoffman.—Geognost. Beobacht.—Archiv. für Min. xiii, 231.

‡ English edition, ii, 188.

If this valley was cut by water, its formation would have extended over a very long period, and the lava must be of a very remote date. This agrees with the circumstance, that the coarse unstratified rock "del Epomeo" at the summit of the mountain, is very much decomposed at many places near Foria, and resembles a pumicestone conglomerate, in which small particles of glassy felspar are imbedded together with laminæ of mica and fragments of lava. It is probable that these rocks are of much more remote date than the year 1302, in which the Corrento del 'Arso flowed from the sides of the Epomeo along near the Castle of Ischia, which is built upon old lava.

XV. Lava of Arso, in Ischia.

The aperture from which this lava flowed is not a true crater, but rather a fissure, the edges of which meet at a sharp angle at the point of eruption, and are indicated by walls scarcely fifty feet high, of dark reddish brown scoriæ and rapilli, between which the lava issued. The rock presents different characters; generally it resembles coarse trachyte, and contains numerous shining, but cracked and broken crystals of glassy felspar, small laminæ of black mica, a few particles of augite, olivine, and magnetic oxide of iron.

	Analysed by
XV A. Very pure glassy felspar crystals from the previous lava.	Abich.[*]
XV B. Portion decomposed by acids.	

Since potash preponderates over soda in Nos. XIV and XV, and still more in the glassy felspar from these rocks, there must be a soda felspar in the matrix of these two lavas.

The lava XIV is undoubtedly of very great age, and the glassy felspar crystals in it, like those in the trachytic conglomerate of the Siebengebirge, are most likely of subsequent production.

The above-mentioned small particles of glassy felspar in the decomposed pumicestone conglomerate, show the condition in which the crystals of this mineral are met with in the remains of decomposed trachytic rocks, and the contrast there is between it and the condition of the crystals in the trachytic and felspathic conglomerate of Rockeskyll.

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[*] Op. cit. p. 44.

	XVI.	XVI A.	XVI B.
Silica	61·19	68·02	40·55
Alumina	17·18	17·46	14·83
Peroxide of iron	5·46	0·97	15·83
Lime	1·52	0·56	4·72
Magnesia	0·23	0·81	1·60
Potash	4·37	4·67	3·31
Soda	7·98	5·98	12·59
Water	1·06	..	4·59
Chlorine	0·68	..	2·84
	99·67	98·47	100·36
O. Q.	0·408	0·322	0·802
Density	2·583	2·632	..

Portion not decomposed by acids	77·05
Portion decomposed by acids	22·95
	100·00

XVI. Lava at Monte Nuovo, erupted from the Lucri lake on the 29th September, 1538.

The eruption continued only seven days, and formed a mountain 413 feet high and 8,000 feet in circumference.* At the foot of the mountain there are scoriaceous and porous masses extending up to the summit, where they pass into true lava, which is scoriaceous above and below for several feet, but solid at the centre, and jointed horizontally like phonolite.

XVI A. Portion not decomposed by acid.

XVI B. Portion decomposed by acid.

	XVII.	XVII A.	XVII B.
Silica	61·71	66·11	41·99
Alumina	19·24	20·70	12·64
Peroxide of iron	3·51	0·64	19·86
Lime	1·19	0·30	4·90
Magnesia	trace	..	2·13
Potash	5·50	5·64	4·83
Soda	7·38	6·15	6·93
Water	1·28	..	5·19
Chlorine	0·15	..	1·03
	99·96	100·24	99·50
O. Q.	0·412	0·362	0·756
Density	2·638	2·624	..

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* De Luc.—Breislak's Lehrb. d. Géol. iii, 16.

XVII. Piperno, bedded with the tuff in the Campi Flegræi.

The rock resembles lava, and occurs along the whole ridge of Pausilipp and Vomero, and in the island St. Stefano, where it is intimately mixed with trachyte.

	Analysed by
XVII A. Portion not decomposed by acid.	Abich.
XVII B. Portion decomposed by acid.	

Since soda preponderates over potash in all these analyses, even the decomposable portion of these lavas cannot be glassy felspar, but at most mixtures of it with soda-felspar.

The lava No. XVI has some resemblance to the phonolite No. IV,* which is also apparent in the portions that are not decomposed by acids, and to some extent in the decomposable portions of these rocks, when the several amounts of the isomorphous bases, alumina and peroxide of iron, are added together. In the phonolite, No. VII, the presence of oligoclase is recognizable, and there is good reason to believe that both felspars are associated in many of these rocks.

All the varieties of augitic lava yet analysed were anhydrous; † but the felspar lava of 1538 at Monte Nuovo contains water. Both the old and recent augitic lava are partially decomposable by acids; the Ætna lava, 167 years old, contains 25 per cent., and that a year old contains from 20 to 26 per cent. of decomposable substance. ‡ The former contains distinct crystals of labradorite and augite, together with small particles of olivine. The latter consists chiefly of labradorite and augite with a few particles of olivine. Therefore the Ætna lava has not undergone alteration either chemical or mineralogical during a period of 167 years; and although the lava at Monte Nuovo has taken up 1·06 per cent. of water in the course of 303 years, it cannot be assumed that the portion decomposable by acids has been produced in consequence of this hydration. A distinction must be drawn between the zeolitic portion of a rock and that which is decomposable by acids; and the presence of the latter is not always accompanied by the presence of water.

These remarks will suffice to show the possibility that a phonolitic rock may originate from felspathic lava. The water taken up by the mass during this change, may be separated at a subsequent time in the same way that this happens with solid substances.

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* See ante, p. 355.

† Ibid. p. 237.

‡ C. v. Hauer.—Sitzungsber. d. k. Acad. d. Wissens zu Wien. xi, 87.

D.—*Trachytic Porphyry of the Ponza Islands in the Mediterranean.*

This rock occurs in large masses in the islands of Ponza, Palmarola, and Zannone; in some of the Lipari Islands it is less pure. In the former localities the connection between the trachytic-porphyry and the other members of the trachytic series is very distinct. There are not, however, any rocks corresponding with the products of existing volcanoes. Those which occur in Ponza, Palmarola, and the Lipari Islands, have undoubtedly been raised above the sea. The following analyses of these rocks are by Abich:—*

	XVIII.	XIX.	XX.	XXI.
Silica	68·35	73·46	74·54	75·09
Alumina	13·92	13·05	13·57	13·26
Peroxide of iron	2·28	1·49	1·74	1·10
Sesquioxide of manganese	..	trace	0·10	..
Lime	0·84	0·45	0·34	0·18
Magnesia	2·20	0·39	0·24	0·16
Potash	3·24	4·39	3·68	8·31
Soda	4·29	6·28	4·86	1·67
Loss by ignition	4·64	..	0·20	..
	99·76	99·51	99·27	99·77
O. Q.	0·281	0·240	0·230	0·217
Density	2·567	2·540	2·529	2·612

XVIII. Trachytic-porphyry lava at Monte Guardia, in Lipari. This rock resembles a compact clay-stone, and often contains imbedded fragments of augitic rock.

XIX. Porphyritic rock in Ponza.

The same rock occurs also in Palmarola, accompanied by the same kinds of pearlite and obsidian, which traverse half-vitrified white fragmentary trachytic rocks, and often appear to alternate with them as irregular layers. Abundance of mica laminæ, and imperfect crystals of felspar are imbedded in the white or grey and reddish-brown matrix, which is sometimes earthy, fine-grained, and soft; sometimes compact, with conchoidal or splintery fracture; sometimes porous and full of small cavities, not unfrequently containing a substance resembling freshly-precipitated alumina and hydrated peroxide of iron.

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* Op. cit. p. 16.

XX. Schistose dyke mass in Palmarola.

This rock is homogeneous, compact, almost earthy, of a light grey colour, and contains very few crystals of glassy felspar. At the joints there are thin ferruginous crusts of felspathic substance, sometimes mixed with very small quartz crystals.

XXI. Porous rock in Zannone.

This occurs both in dykes and as a massive rock; it is much fissured, and rises to the summit of the range of rocks extending longitudinally through the island. It is of a reddish-yellow colour, and at the conchoidal, splintery, or earthy fracture, contains shining crystals of felspar and quartz. At the interior there are compact masses of quartz and quartz crystals in open fissures. In this island there are not any vitreous masses, pumice conglomerate, or tuff.

The rocks Nos. XVIII to XX must contain a soda-felspar, together with glassy felspar, since soda preponderates over potash; but in No. XXI this cannot be the case. Abich considers that this rock contains orthoclase. All these rocks contain quartz.

E.—*Trachytic Rocks of Teneriffe.*

	XXII.	XXIII.	XXIV.
Silica	57·76	52·80	59·26
Alumina	17·56	16·79	21·04
Peroxide of iron	4·64	..	..
Protoxide of iron	2·09	14·68	4·23
„ manganese	0·82		
Lime	5·46	3·55	1·29
Magnesia	2·76	trace	trace
Potash	1·42	2·95	4·67
Soda	6·82	7·18	8·49
Water	trace	..	..
Chlorine	0·30	..	..
	99·63	97·95	98·98
O. Q.	0·485	0·526	0·425
Density	2·749	..	..

Analysed by

XXII. Rock of the circus of the Peak of Teneriffe. } Abich.*

Fine-grained mass, of a grey colour, containing numerous crystals of glassy felspar, hornblende, and magnetic oxide of iron.

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* Op. cit. p. 103.

Analysed by

XXIII. Trachyte of the Cahorra crater at the centre of the Peak.
XXIV. Lava of Cahorra. } Deville.*

	XXV.	XXVI.	XXVII.
Silica	59·71	60·26	57·88
Alumina	19·23	20·25	19·09
Protoxide of iron	5·48	4·79	8·92
„ manganese	0·30	0·78	0·82
Lime	0·58	0·86	3·65
Magnesia	trace	0·30	trace
Potash..	14·70	12·76	9·64
Soda			
	100·00	100·00	100·00

Analysed by

XXV. Obsidian at the Peak of Teneriffe.
XXVI. Obsidian at the Piedras blancas.
XXVII. Lava at Portillo. } Deville.*

Abich considers that the rock No. XXII contains oligoclase, but since there is 2·87 per cent. silica in excess, it must also contain quartz, or a felspar to which this excess belongs. Deville showed that the felspar crystals of all these rocks are really oligoclase. This is also indicated by the great preponderance of soda over potash; and since the composition of No. XXV corresponds so closely with that of No. LXXXVIII, there can be no doubt that soda preponderates in that obsidian.

The close correspondence of Nos. XXIV, XXV, and XXVI, is strikingly illustrative of the possible production of obsidian from the adjoining lava. Notwithstanding the considerable difference between Nos. LXXXVIII and LXXXIX, the production of pumicestone from obsidian is also probable.

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* Etudes Géologique sur les Iles de Teneriffe. Paris, 1848.

F.—*Trachytic Rocks of the Central Cone of Soufrière, in Guadeloupe.*

	XXVIII.	XXIX.	XXX.	XXXI.	XXXII.
Silica	57·95	74·11	69·00	48·71	48·68
Alumina	15·45	10·44	9·69	20·00	19·34
Protoxide of iron	9·45	6·25	8·39	11·25	7·85
„ manganese ..	1·40	0·78	trace	2·94	3·24
Lime	8·30	2·12	3·32	10·95	12·83
Magnesia	2·35	0·44	3·18	2·70	3·55
Potash	0·56	1·15	1·52	0·38	4·51
Soda	3·03	4·84	3·32	3·08	
	98·49	100·13	98·42	100·01	100·00
O. Q.	0·458	0·224	0·270	0·693	..
Density	2·75	..	..	2·907	2·904

Analysed by

XXVIII. Rock of the inner cone of the Soufrière. } Deville.*

This rock is accompanied by pumice and obsidian, but contains labradorite and quartz, together with olivine and magnetic oxide of iron. Deville regards it as trachytic dolerite.

XXIX. The above-mentioned obsidian, which is converted into pumicestone when heated.

XXX. Pumicestone originating from a trachytic rock.

XXXI. Dark grey or blackish dolerite from the summit of the crater of elevation of the Soufrière.

This rock contains labradorite, augite, olivine, magnetic oxide of iron, etc., and 0·89 per cent. of water.

XXXII. Dolerite in the neighbourhood of the above.

This rock is slightly altered at the surface, and contains 1·52 per cent. water. Before the analysis 3·5 per cent. magnetic oxide of iron was separated.

The preponderance of soda over potash in all these rocks renders the production of obsidian from trachyte intelligible, but the larger amount of quartz in XXIX as compared with XXVIII still remains to be accounted for.

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* Bull. Géol. (2) viii, 426.

G.—*Trachytic Rocks in Iceland.*

The composition of the principal members of the volcanic rocks of Iceland is well shown by the comprehensive investigations of these rocks by Bunsen.*

The principal mass of these rocks is amorphous, and they present the appearance of very intimate and uniform mixtures.

	XXXIII.	XXXIV.	XXXV.	XXXVI.	XXXVII.	XXXVIII.
Silica	74·38	74·77	75·91	77·92	75·29	78·95
Alumina	13·78	13·57	11·49	12·01	12·94	10·22
Peroxide of iron ..	1·94	1·92	2·13	1·32	2·60	2·91
Sesquioxide of manganese ..	0·19	trace	..	..	..	..
Lime	0·86	0·81	1·56	0·76	1·01	1·84
Magnesia	0·59	0·53	0·76	0·13	0·08	0·14
Potash	2·63	2·87	5·64	3·27	5·42	1·76
Soda	3·57	4·74	2·51	4·59	2·71	4·18
Water	2·09	0·67	..	..	..	..
Chlorine	0·13	..	..	..	..	..
	100·16	99·88	100·00	100·00	100·00	100·00
O. Q... ..	0·230	0·232	0·207	0·195	0·225	0·187

	Analysed by
XXXIII. Greyish-white porous rock of the trachytic cone Baula.	Forchhammer.†
XXXIV. The same rock.	Kjerulf.

XXXV. The same rock where it is white, and sometimes with a yellow or blue tinge, and coarse, with numerous small cavities.

XXXVI. Rock at Strutrhals, near Kalmanstunga.

This rock occurs as a perpendicular cliff traversed by trapp dykes, and irregularly fissured. It is pure white, has a distinct crystalline structure, and resembles the previous rock.

XXXVII. Rock at Langarfjall, at the Great Geiser.

This rock is columnar, compact, of a blueish-grey colour, with a few particles of felspar and hornblende crystals imbedded in it.

XXXVIII. Trachyte at the Arnarhnipa, on the banks of the Laxa.

This rock resembles No. XXXVI, but is yellower, finer grained, and rather earthy.

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* Poggend. Annal. lxxxiii, 197.

† Journ. f. prakt. Chemie, xxx, 391.

	XXXIX.	XL.	XLI.	XLII.	XLIII.
Silica	76·42	76·38	75·77	78·32	76·65
Alumina	9·57	11·53	10·29	12·64	11·57
Protoxide of iron	5·10	3·59	3·85	..	0·63
Peroxide of iron	..	..	..	1·57	..
Lime	1·53	1·76	1·82	1·29	0·05
Magnesia	0·20	0·40	0·25	0·96	0·20
Potash	1·94	1·88	2·46	2·35	3·26
Soda..	5·24	4·46	5·56	3·59	3·73
.. ..	100·00	100·00	100·00	100·72	96·09
O. Q.	0·196	0·209	0·206	0·207	0·180

XXXIX. Clinkstone at Falkaklettur, near Kalmanstunga.

The mass of this rock is compact, greyish-brown, speckled or streaked with oxide of iron, and contains but few traces of imbedded felspar.

XL. Lava at Hrafntinnuhryggr, near Krafla.

This lava appears to be very recent. It is blackish-grey, homogeneous, and stony, with a number of small irregular cavities.

XLI. Black homogeneous obsidian, alternating with the lava.

The last seven analyses are by Bunsen.

XLII. White granular substance ejected at remote periods from the Viti volcano.

It consists of hornblende, with a white mineral amounting to nine-tenths of the whole, and a few crystals of quartz. Forchhammer.*

XLIII. A white mineral, carried down from the interior of the Jökulaue.

The rocks Nos. XXXIII, XXXIV, XXXVI, XXXVIII, XXXIX, XL, XLI, XLII, and XLIII, certainly contain felspar rich in soda, together with glassy felspar. In XXXVII perhaps there is only glassy felspar. All these rocks must contain considerable amounts of quartz.

H.—*Trachytic Rocks in the Highlands of Armenia.*

The analyses of these rocks have been made by Abich.

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* Op. cit. p. 392.

	XLIV.	XLV.	XLVI.	XLVII.
Silica	61·13	65·21	65·26	65·46
Alumina	16·44	14·16	15·35	15·36
Protoxide of iron	9·23	6·70	7·26	6·65
Lime	6·25	6·56	7·39	4·24
Magnesia	3·76	3·47	2·99	2·11
Potash	2·99	3·80	1·56	1·33
Soda..				4·09
Loss by ignition	0·44	0·20	0·30	0·34
	100·24	100·10	100·10	99·58
O. Q.	0·432	0·358	0·366	0·346
Density	2·760	2·707	2·632	2·635

XLIV. Very compact hard rock between Keschet and Kobi.

By the aid of the magnifying glass, it appears as an intimate mixture of a dark grey crystalline mass, with small needles of felspar and particles of magnetic oxide of iron.

XLV. Reddish-brown rock at Ararat.

This appears as a perfectly scoriaceous, and very porous mass, with small patches semi-scoriaceous, and numerous shining crystals imbedded in it. It is magnetic.

XLVI. Porous rock at Ararat, resembling doleritic lava.

The very compact fine-grained mass is crystalline, with shining felspar crystals imbedded in it. It is very magnetic.

XLVII. Coarse-grained crystalline rock at Ararat.

The compact, blackish-grey mass resembles hornstone, and contains numerous felspar crystals with a glassy lustre, a few particles of hornblende and mica, and distinct traces of iron pyrites and magnetic oxide of iron.

	XLVIII.	XLIX.	L.	LI.
Silica	69·47	69·37	69·25	70·25
Alumina	14·98	14·44	13·34	13·49
Protoxide of iron	3·35	5·32	4·79	..
Peroxide of iron		..		4·95
Lime	4·68	4·38	5·09	4·20
Magnesia	0·98	2·26	1·64	1·52
Potash	1·46	3·82	1·81	5·07
Soda	4·46		3·32	
Loss by ignition	0·35	0·60	0·65	0·67
	99·73	100·19	99·90	100·15
O. Q.	0·306	0·306	0·300	0·312
Density	2·595	2·546	2·643	2·616

XLVIII. Rock at the summit of the Great Ararat.

Crystalline, fine-grained, and not very hard. A great number of extremely small crystals of glassy felspar are recognizable at the fracture, and there are a few crystals of hornblende. It is slightly magnetic.

XLIX. Rock at the summit of Elbrouz.

The dark-coloured mass contains numerous crystals of felspar, hornblende, mica, and magnetic oxide of iron.

L. Rock at the summit of the Kasbek; dark-brown variety.

The surface of this rock is very smooth, and the fracture is perfectly crystalline. It contains numerous striated crystals of felspar, a few particles of hornblende, and traces of mica. It is slightly magnetic.

LI. The reddish-brown variety of the same rock.

Fine-grained, crystalline, rough at the fracture; the lighter coloured portions are porous and friable. It is sensibly magnetic, and contains distinct crystal of hornblende, together with shining felspar crystals and a few scales of mica.

	LII.	LIII.	LIV.
Silica	76·66	61·92	57·67
Alumina	12·05	14·10	11·94
Protoxide of iron	3·47	6·22	6·41
Peroxide of iron		..	..
Protoxide of manganese	..	0·20	0·30
Lime	1·25	6·03	7·72
Magnesia	trace	5·27	7·02
Potash	2·94	0·61	
Soda	3·53	4·88	
Loss by ignition	1·12	..	..
	101·02	99·23	91·60
O. Q.	0·209	0·374	..
Density	2·656	2·778	2·775

LII. Rock at Besobdal.

The light-coloured matrix resembles hornstone, and contains numerous milky crystals with the form of albite, crystalline particles of quartz, with finely disseminated magnetic oxide of iron, and traces of a mineral that has become unrecognizable in consequence of decomposition. The close correspondence between obsidian and this rock shows that it may be produced from such masses.

The rocks Nos. XL to XLVII are distinguished from true trachyte and trachytic porphyry by the presence of considerable amounts of lime and magnesia, as well as by the preponderance of soda over potash. They appear to be more analogous to the trachytic rocks of Hungary and Styria, those of the circus round the Peak of Teneriffe, of Cahorra, and in Guadeloupe. According to Abich's account, none of the rocks in Armenia appear to contain glassy felspar. Independently of the crystallographic characters, the presence of calcareous felspar, either oligoclase or labradorite, is indicated by the large amount of lime and soda in a rock that can only contain small quantities of other calcareous minerals.

Abich calculates, from the results of his analyses, the relative quantities of the mineral constituents; and, in this way, it appears that XLIV and XLVI contain labradorite, XLV and XLVII oligoclase, XLVIII and XLIX albite, L and LI either oligoclase or albite, and that the whole of these rocks contain also, uncombined silica, hornblende, and magnetic oxide of iron.

The presence of labradorite in a trachytic rock, is indicative of conversion into basaltic or doleritic rock. A rock of this kind at Ararat, containing much augite and magnetic oxide of iron, but already somewhat altered, is mentioned by Abich as occurring next to the rock XLVI, in which also, he is of opinion, that labradorite is present. In this instance there appears to be a relation between these rocks similar to that between the trachytic rock containing labradorite, and the dolerite at Guadeloupe. In the Siebengebirge there is a similar relation. The rock of the Löwenburg appears to be intermediate between dolerite and trachyte, and contains:—

Silica	55·17
Alumina	13·56
Magnetic oxide of iron	14·35
Lime	7·04
Magnesia	3·89
Potash	1·87
Soda	3·20
Loss by ignition	0·92
Traces of chlorine, sulphuric and phosphoric acids	
O. Q.	0·534

Bunsen met with a great number of such mixed rocks in Iceland, and determined, by a numerous series of analyses, the compositions of the normal trachytic and pyroxenic rocks, so as to be able to calculate the relative proportions of these constituents in the mixed rocks. Extending this calculation to the rocks of the Armenian Highlands, they also appear to be mixed rocks. This induced him to assume the existence of two volcanic foci, the one yielding pure trachyte and the other pyroxenic material. This distinction of rocks corresponds with the former distinction adopted by geologists between felspathic and augitic lava. Streng[*] describes the occurrence of such mixed rocks in the Faroe islands, in Ireland, Scotland, and Hungary.

These rocks, which partake of the character of both trachyte and dolerite, are characterized by Abich by the name of trachytic dolerite. They may be distinguished apparently as hornblendic and augitic varieties.[†] The former comprises the rocks at the Peak of Teneriffe, the Schivelutsch in Kamtschatcha, the island of Lisca-Nera, those in the Highlands of Armenia, and many of the older lavas at Ætna; the latter comprises the rocks constituting the craters of elevation at Stomboli and Roccamonfina, and at the Tunguragua in Quito.[‡]

LIII. The dyke and massive rock at Schivelutsch in Kamtschatcha.

The fine-grained crystalline matrix contains small glassy crystals, hornblende, augite, and magnetic oxide of iron. There are two kinds of felspar, one similar to oligoclase, the other consisting of small shining crystals with twin angles.[§]

LIV. Rock in the island of Dattolo.

The dark-brownish red mass contains numerous crystals of two kinds of felspar, with a few crystals of hornblende, and some magnetic oxide of iron.

I.—*Trachytic Rocks in the Andes.*

	LV.	LVI.
Silica	65·09	67·07
Alumina	15·58	13·19
Peroxide of iron	3·83	4·74
Protoxide of iron	1·73	..
Sesquioxide of manganese	..	0·32
Lime	2·61	3·69
Magnesia	4·10	3·46
Potash	1·99	2·18
Soda	4·46	4·90
Loss by ignition	0·41	0·30
	99·80	99·85
O. Q.	0·373	0·335
Density	2·685	2·580

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[*] Poggend. Annal. xc, 117.

[†] Naumann.—Geognosie, i, 642.

[‡] Abich.—Op. cit. p. 100.

[§] Ibid. p. 106.

Analysed by

LV. Andesite—The rock at the summit of Chimborazo. } Abich.*

The grey compact mass contains many small crystals of albite and rather large crystals, apparently of glassy felspar, together with a few particles of hornblende and augite and purely disseminated magnetic oxide of iron.

LVI. The same kind of rock at the summit of the Pichincha.

The dark-coloured mass resembling pitchstone, contains narrow crystals of albite, augite, and particles of magnetic oxide of iron.

Both rocks resemble much the mass of the Drachenfels trachyte, but the soda preponderates more in the latter. Therefore Abich infers that the albite must amount to about three times as much as the glassy felspar in No. LV. When this trachyte was long digested with hydrochloric acid, there remained a perfectly crystalline residue containing 67·87 per cent. silica. This is the same as the amount of silica in glassy felspar, but less than that in albite; so that it does not correspond with the assumed considerable proportion of albite, or even of oligoclase.

K.—*Pearlstone and Pitchstone.*

Pearlstone constitutes peculiar rocks, consisting of nodules, sometimes with concentric layers.† It is of various shades of grey, yellow, red, brown, and but rarely contains particles of glassy felspar, or mica scales, and sometimes quartz crystals. Among the accessory minerals are hornstone, jasper, and opal, as nests and veins.

Pitchstone occurs both as a rock, and as dykes and beds, in various rocks. It is of coarse texture, granular or compact, seldom columnar, and generally of various shades of green. The pitchstone porphyry contains crystalline particles of felspar, quartz, and laminæ of mica. It also contains at some places calcedony and hornstone, as nests and veins.

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* Géol. Beob. p. 53.

† Beudant.—Vogage Min. et Geol. en Hongrie. The occurrence of pearlite is especially remarkable near Tokay, where it extends over an area of twelve square miles.

	LVII.	LVIII.	LIX.	LX.
Silica	75·25	77·0	72·87	77·20
Alumina	12·00	13·0	12·05	12·47
Peroxide of iron	1·60	2·0	1·75	2·27
Sesquioxide of manganese ..	..		..	..
Lime	0·50	1·5	1·30	3·34
Magnesia	..	..	1·10	0·73
Potash	4·50	2·7	trace	4·27
Soda	..	..	6·13	
Water	4·50	4·0	3·00	..
	98·35	100·2	98·20	100·28
O. Q.	..	..	0·225	..
Density	2·34	2·254	2·371	2·416

Analysed by

LVII. Pearlstone between Keristur and Tokay } Klaproth.*

This rock is of an ash-grey colour, with yellowish streaks, and occurs as beds, alternating with clay porphyry.

LVIII. Pearlstone at Cinapecuaro, in Mexico } Vauquelin.†

LIX. Pearlstone at Hlinik, near Schemnitz, in Hungary
LX. Brown sphærulite, from the last-named pearlstone } O. L. Erdmann.‡

This is sometimes blended with laminæ of mica, and surrounds a nucleus of quartz.

	LXI.	LXII.	LXIII.	LXIV.
Silica	79·12	68·53	74·83	74·22
Alumina	12·00	11·00	13·49	13·20
Peroxide of iron	2·45	4·00	4·40	2·50
Protoxide of manganese	..	2·30	..	..
Lime	..	8·33	1·98	..
Magnesia	1·10	1·30	0·17	0·99
Potash	3·58	3·40	little	1·08
Soda			5·56	5·80
Water	1·76	0·30	..	2·99
	100·01	99·16	100·43	100·78
O. Q.	..	..	0·250	0·213
Density	..	2·574	2·389	2·508

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* Beiträge, iii, 326. † n. allgem. Journ. für Chemie, v, 230.
‡ Journ. für techn. Chemie, xv, 40.

Analysed by

LXI. Sphærulite from the same pearlstone Ficinus.*

This is globular, partly grey or yellow, of a radiated fracture, and covered with laminæ of black mica.

LXII. Globular masses from the pitchstone at Spechthausen, near Tharand } O. L. Erdmann.

These consist of alternate reddish-brown, and ash-grey layers, surrounding a brown nucleus, but without radiated structure.

LXIII. Globular masses from the obsidian at Hrafntinnahruggr } Forchhammer. †

These have a concentric radiated structure.

LXIV. Globular radiated masses from Iceland } Forchhammer.

	LXV.	LXVI.	LXVII.	LXVIII.
Silica	73·00	73·00	75·60	72·80
Alumina	14·50	10·84	11·60	11·50
Peroxide of iron	1·00	1·90	1·20	3·03
Sesquioxide of manganese	0·10	..	traces	..
Lime	1·00	1·14	1·35	1·12
Magnesia	..	..	0·73	..
Soda	1·75	1·48	..	2·88
Potash	..	..	2·77	..
Water	8·50	9·40	4·73	8·50
	99·85	97·76	97·98	99·83
O. Q.	0·207	0·167	..	0·210
Density	..	..	..	2·857

Analysed by

LXV. Pitchstone in the Triebitsch Valley, near Meissen } Klaproth.‡

This specimen analysed was translucent and yellowish, or olive green.

LXVI. Dark-coloured pitchstone in the same locality } Du Menil.§

LXVII. Light brown pitchstone in the same locality } O. L. Erdmann.||

LXVIII. Pitchstone at Newry Knox.¶

This rock contained bituminous substance. Ficinus ** found

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[*] Schweigg. Journ. xxix, 136.

[†] Journ. für prakt. Chemie, xxx, 394.

[‡] Beiträge, iii, 257.

[§] Schweigg. Journ. xxvi, 387.

[||] Op. cit. p. 41.

[¶] Edinb. Journ. of Science, xiv, 382.

[**] Schweigg. Journ. xxxvii, 435.

this to be the case also with the pitchstone at Meissen and Damour.

	LXIX.	LXX.
Silica	66·59	67·90
Alumina	11·71	11·20
Protoxide of iron	3·93	..
Peroxide of iron	..	6·40
Protoxide of manganese	0·12	..
Sesquioxide of manganese	..	0·80
Lime	0·71	3·10
Magnesia	0·36	..
Potash	3·65	..
Soda	5·94	2·61
Water, and volatile substance ..	4·86	8·00
	97·87	100·01
O. Q.	0·256	0·252
Density	..	2·375

	Analysed by
LXIX. Glassy pitchstone at Baula, in Iceland	Kjerulf.

This constantly accompanies the trachytic porphyry of Iceland.

LXX. Pitchstone porphyry at the Isle Royale, Lake Superior	C. F. Jackson.*

The composition of pearlstone and pitchstone approximates to that of trachytic porphyry, except that the amount of alkalies is less, and that potash appears to be wanting, or but very scanty. The presence of bituminous substance,† and a large amount of water in pitchstone shows that there has been considerable alteration going on. This is likewise apparent from the concentric scaly structure which is generally the result of decomposition.

If pearlstone is decomposed trachytic porphyry, which is probable, from its constant occurrence near the latter, and among true trachyte, the potash must have been removed during the alteration. This again points to the probable conversion of silicate of potash into silicate of soda, by reaction with chloride of sodium, which has been so often mentioned. There must have been also some decomposition of the alkaline silicates, because the amount of alkalies is reduced, and the hornstone, jasper, and opal, probably originate from silica thus eliminated. The same remarks apply to pitchstone, which is more closely related to felspar porphyry than to trachytic rocks, although it sometimes passes into pearlstones.

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* Silliman's Amer. Journ. (2) xi, 401.

† The pitchstone at Zwickau sometimes contains charred remains of plants.

L.—*Obsidian and Pumicestone.*

Although the physical characters of obsidian, and the circumstance that melted trachyte or basalt yield, when rapidly cooled, masses similar to obsidian, appear to favour the opinion that this rock has been produced in the same manner, it is difficult to reconcile this view with the occurrence of obsidian granules in pearlstone, and of sphærulite in obsidian. If pearlstone is decomposed trachytic porphyry, the obsidian in it must have a similar origin, or have been produced from the pearlstone, and in either case it is impossible to suppose that there was any partial fusion.

The obsidian from true obsidian streams at Teneriffe, No. LXXXVII, contains a number of white felspar crystals, which are so abundant at the under parts of the mass, that the lava resembles a crystalline rock in appearance.[*] There are varieties of obsidian that are quite as difficult to melt as felspar—some which melt much more easily. Consequently, if the obsidian containing the crystals is of the more fusible kind, which is probable, from the fact that it contains a large amount of alkalies, it might be inferred that the felspar crystals were present in the melted mass, if it were not that melted obsidian would act as a flux upon the felspar.

There can be no question as to the volcanic origin of the pumicestone at Vulcano and Lipari, as well as of that at the lake of Laach. Nevertheless, a product closely resembling pumicestone[†] may result from the weathering of cellular trachyte. Weathered trachyte of this kind occurs in the trachytic conglomerate of the Siebengebirge.[‡] Beudant's pearlite-pumicestone is probably of this nature.[§]

Abich found that obsidian is converted into pumicestone by fusion, more readily in proportion as it contained less silica and more alkalies. The powdered obsidian did not swell up when heated to redness as the lumps did, and it lost only half as much in weight.

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[*] Abich.—Geol. Beob. p. 71. Reinwardt also found crystalline granules of glassy felspar, and sometimes fragments of quartz, in the pumicestone of Java, where it is always associated with trachytic rocks. Poggend. Annal, xii, 616.

[†] v. Dechen.—Op. cit. p. 457.

[‡] Nöggerath.—Rheinland-Westphalen, i, 130.

[§] Naumann.—Geognosie, i, 627.

	LXXI.	LXXII.	LXXIII.	LXXIV.
Silica	81·00	77·50	78	69·46
Aluminia	9·50	11·75	10	2·60
Peroxide of iron	0·60	1·25	2	2·60
Protoxide of manganese ..	..	..	1·6	..
Lime	0·33	0·50	1	7·54
Magnesia	..	..	..	2·60
Potash	2·70	7·00	6	7·12
Soda	4·50		..	5·08
Water	0·50	0·50	..	..
Volatile substance	..	..	..	3·00
	99·13	98·50	98·6	100·00
O. Q.'	0·150	..	0·171	0·213
Density	2·365	2·335	..	..

Analysed by

LXXI. Transparent marekanite from the Marekanka brook Klaproth.[*]

This mineral occurs as detached granules in pearlstone.

LXXII. Opaque marekanite from the same place Klaproth.

This was dark brown and blueish black, with red streaks and spots. Klaproth considered it to be obsidian, and showed its correspondence with pearlstone in composition.

LXXIII. Obsidian at Cerro de las Navajas, near Mexico Vauquelin.[†]

LXXIV. Obsidian at Pasco Berthier.[‡]

	LXXV.	LXXVI.	LXXVII.	LXXVIII.
Silica	82·70	74·80	75·64	70·34
Alumina	9·40	12·40	10·64	8·63
Peroxide of iron	2·61	2·03	1·36	..
Protoxide of iron	..	..	..	10·52
" manganese	0·13	1·31	4·00	0·32
Lime	1·21	1·96	2·50	4·56
Magnesia	1·21	0·90	0·71	1·67
Soda	2·45	6·40	3·30	3·34
Potash	..			..
Water	..	..	0·25	..
	99·71	99·80	98·40	99·38
O. Q.	0·155	..	..	0·254
Density	..	2·362	..	2·47

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[*] Beiträge, vi, 353.

[†] n. allg. Journ. d. Chemie, v, 230.

[‡] Ann. des Mines (3) v, 543.

Analysed by

LXXV. Obsidian at Moldauthein, in Bohemia — O. L. Erdmann.[*]

Transparent, green coloured, and with vitreous lustre.

LXXVI. Obsidian at Felköbanga — O. L. Erdmann.[*]

Black, with vitreous lustre, occurs as round lumps imbedded in pearlstone.

LXXVII. Mineral resembling obsidian in the pitchstone of Bräunsdorf, near Tharand

LXXVIII. Black Indian obsidian — Damour.[†]

Thin fragments had a dark olive green-colour; when cut, it exploded like unannealed glass drops.

	LXXIX.	LXXX.	LXXXI.	LXXXII.	LXXXIII.
Silica	75·20	70·97	79·40	51·19	39·74
Alumina	6·86	6·77	11·25	..	10·55
Peroxide of iron	6·54	6·24	4·30	..	22·29
Protoxide of iron	..	..	..	30·26	..
Lime	3·83	2·84	1·75	..	2·74
Magnesia		1·77	..	18·16	2·40
Potash	7·57	11·41	..	..	..
Soda			3·03	..	21·62
Water	..	..	..	..	0·33
	100·00	100·00	99·73	99·61	99·67
O. Q.	..	..	0·190	0·521	0·830

Analysed by

LXXIX. Obsidian at the Inselbai, New Zealand — Murdock.[‡]

LXXX. Obsidian in the Island of Ascension — Murdock.

LXXXI. Black obsidian constituting a hill in Java — van der Boon Mesch.[§]

This has a glassy lustre, and consists partly of laminæ, alternating with half devitrified light-coloured streaks, as is often the case with the obsidian at Lipari. At some parts it is full of cavities containing small, white spherules, like pearlstone.

[*] Op. cit. p. 36.

[†] Poggend. Annal. lxii, 287.

[‡] Berg—und Hüttenmännische Zeitung, 1846, p. 90.

[§] Poggend. Annal. xii, 616.

Analysed by

LXXXII. Capillary obsidian at Hawai } B.Silliman.[*]
LXXXIII. Vitreous obsidian

	LXXXIV.	LXXXV.	LXXXVI.	LXXXVII.
Silica	57·89	56·47	50·06	58·02
Alumina	19·12	19·40	18·34	129·5
Protoxide of iron	2·45	3·54	2·89	9·51
Sesquioxide of manganese ..	..	trace	trace	trace
Lime	1·21	0·67	1·29	1·92
Magnesia	1·10	0·72	1·17	1·18
Potash	9·23	3·12	5·81	0·13
Soda	6·65	11·17	4·41	1·87
Water	2·40	5·24	15·06	15·02
	100·05	100·33	99·11	100·60
O. Q.	0·455	0·476	0·477	0·345
Insoluble portion	13·14	17·78	17·74	24·20
Density	2·031	1·702	1·74	2·06

Analysed by

LXXXIV. Pumicestone at the Krufter Ofen, near the lake of Laach } R. F. Schäffer.

This contains admixtures of glassy felspar, hauyn, and a few hornblende crystals.

LXXXV. Pumicestone at Neuwied.

Mixed with small fragments of clay-slate, glassy felspar, and traces of hauyn or nosean.

LXXXVI. Pumicestone at Engers, with traces of glassy felspar } F. R. Schäffer.[†]
LXXXVII. Pumicestone fragmentary rock at Gisselberg, near Marburg

Small particles cemented by argillaceous material.

Hydrochloric acid left an insoluble residue. Schäffer found many deposits of pumicestone in the Ohm valley, near Marburg and Giessen, which originate from the eruptions in the vicinity of the lake of Laach, principally from the Krufter Ofen. This pumicestone has been partly carried by the wind, and partly by water, from the Upper Lahn Valley, and has the same origin as the pumicestone of Nassau. Schäffer infers from his analyses, that the proportion of alumina and peroxide of iron to silica is nearly

[*] Dana's Mineral, p. 329.

[†] Die Bimstein Körner bei Marburg, etc. Jahresb. 1851, p. 862.

constant; but that the proportion of other bases to silica varies in consequence of the action of the atmosphere and water.

Abich* has made a number of analyses of obsidian and pumicestone, and separates them into two classes:—

First Class.—Nos. LXXXVIII to XCIV.—Frothy pumice-stone, dirty white and greyish-green.

	LXXXVIII.	LXXXIX.	XC.	XCI.
Silica	60·52	60·79	61·08	62·42
Silica with titanic acid	0·66	1·46	1·45	0·74
Alumina	19·05	16·43	17·37	14·72
Peroxide of iron	4·22	4·26	7·77	6·84
Sesquioxide of manganese	0·33	0·23	0·62	0·18
Lime	0·59	0·62	1·46	3·25
Magnesia	0·19	0·79	4·02	3·28
Potash	3·50	2·97	1·82	1·55
Soda	10·63	11·25	2·85	4·74
Water	0·04	0·53	1·63	2·41
Chlorine	0·30			
	100·03	99·33	100·07	100·12
O. Q.	0·434	0·444	0·454	0·385
Density	2·528	2·477	1·983	2·571

LXXXVIII and LXXXIX. Obsidian of Teneriffe.
XC. Obsidian in the island Ferdinandea.
XCI. Obsidian at the volcano of Arequipa.

	XCII.	XCIII.	XCIV.	XCV.
Silica	62·29	62·70	62·04	68·11
Silica with titanic acid	..	..	..	1·23
Alumina	16·89	16·98	16·55	8·21
Peroxide of iron	4·15	4·98	4·48	8·23
Sesquioxide of manganese	trace	0·39	..	trace
Lime	1·24	1·77	1·31	0·14
Magnesia	0·50	0·82	0·72	0·37
Potash	8·98	6·09	3·66	1·60
Soda	6·21	4·35	6·29	8·32
Water	8·89	0·76	3·84	1·73
Chlorine		0·52		0·70
	99·15	99·36	98·94	98·64
O. Q.	0·362	0·394	0·400	0·274
Density	2·417	2·490	2·411	2·530

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* Op. cit. p. 62.

XCII. Pumicestone of Ischia.
XCIII. Pumicestone of the island Procida.
XCIV. Pumicestone of Campi Flegræi.

Second Class.—Nos. XCV to XCIX.—Fibrous or capillary pumicestone, white, with a silky lustre.

XCV. Pumicestone of the island Pantellaria.

	XCVI.	XCVII.	XCVIII.	XCIX.
Silica	69·79	73·77	73·70	74·05
Alumina	12·31	10·83	12·27	12·97
Peroxide of iron	4·66	1·80	2·31	2·73
Lime	1·68	1·21	0·65	0·12
Magnesia	0·68	1·30	0·29	0·28
Potash	2·02	3·90	4·73	5·11
Soda	6·69	4·29	4·52	4·15
Water	2·93	2·85	1·22	0·22
Chlorine			0·31	0·31
	100·76	99·95	100·00	99·94
O. Q.	0·274	0·225	0·235	0·235
Density	2·355	2·224	2·377	2·370

XCVI. Pumicestone of the island Santorin.
XCVII. Pumicestone of Llactacunga.
XCVIII. Pumicestone of Lipari.
XCIX. Obsidian of Lipari.

	C.	CI	CII.
Silica	77·27	77·42	77·60
Alumina	11·85	12·08	11·79
Peroxide of iron	2·55	3·05	2·17
Lime	1·31	2·73	1·40
Magnesia	trace	trace	..
Potash	2·44	4·32	2·30
Soda	4·15		4·21
Loss by ignition	0·51	0·57	0·61
	100·08	100·17	100·08
O. Q.	0·203	0·211	0·198
Density	2·358	2·363	2·394

C. Brown obsidian at the Lesser Ararat.
CI. Perfectly homogeneous black obsidian at Kiotangdag.

This is similar to the obsidian of Lipari.

CII. Obsidian porphyry at the Great Ararat.

The mass of this rock is more like pitchstone than obsidian, and contains numerous twin crystals resembling albite.

The quantitative relation of the several constituents of obsidian and pumicestone are the same as in trachytic rocks generally, so that it is possible any trachytic rock may be converted into obsidian and pumicestone.

The pumice-stone Nos. LXXXIV to LXXXVII contain in the anhydrous state 59·28, 59·39, 59 56, and 67·8 per cent. silica. Except in the last instance, these numbers agree tolerably, but they show that these specimens of pumicestone contain the smallest amount of silica. The volcanic rocks in the neighbourhood of the lake of Laach, being augitic, and not felspathic, contain still less silica—45 to 50 per cent.—but much protoxide of iron—12 to 23 per cent.—and from 7·5 to 9 per cent. lime. From such lava the pumicestone Nos. LXXXIV to LXXXVI could not have been produced. On the contrary, the volcanic bombs which seem to have been thrown out of the crater on the Krufter Ofenberg, next to the lake of Laach,* contain abundance of glassy felspar, so that the material from which these masses were produced might have given rise to the above-mentioned pumicestone, since the composition of No. LXXXIV corresponds very closely with that of glassy felspar. Moreover, the occurrence, in a volcanic district, where the lava is all augitic, of glassy felspar, the preponderating constituent of trachytic rocks, is remarkable, and agrees with the frequently observed transition of trachytic into doleritic rocks.

Pumicestone is more exposed to decomposing agents than almost any other kind of rock, in consequence of its vesicular and porous character, and pumicestone, which differs considerably in composition from the rocks adjoining it may, nevertheless, have originated from them. At Nickenich, the undermost beds of pumicestone are encrusted with calcareous sinter, originating most likely from the decomposition of pumicestone higher up.

The production from trachytic lava, of the pumicestone and obsidian belonging to the first class, is easily intelligible, on account of their similarity in composition. A similar resemblance exists between those of the second class and trachytic porphyry.

Abich points out that comparing the composition of obsidian with that of pumicestone corresponding with it, the sum of the alkalies appears to be much the same, but that in the pumicestone the amount of potash is less than that of soda. A comparison of the analyses Nos. LXXXIV, LXXXV, and LXXXVI, which represent pumicestone of the same origin, shows that in the course of time the greater part of the potash is displaced by soda. The pumicestone in the Krufter Ofen is at the surface; but near Engers and Benndorf, the pumice-stone conglomerate is from thirteen to twenty-two feet below the marly soil and volcanic sand, and the chloride of sodium in the water has converted the silicate of potash into silicate of soda.

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* Von Oeynhausen.—Erläuterungen zu der Geognost. orograph. Karte der Umgebung des Laacher-See. p. 54.

The presence of 15 per cent. of water in the pumicestone analysed by Schäffer, shows most distinctly that volcanic products may become hydrated, and this change is evidently connected with a diminution of the portion soluble in acids.

M.—*Trachytic Tuff.*

These rocks are distinctly stratified, generally white, or pale grey, with a yellowish-red or green tinge. They not unfrequently contain nests or veins of opal, and sometimes plant remains. The trachytic tuff contains, according to Abich [*] :—

	Undecomposable by acids.	Decomposable by acids.
CIII. Yellow tuff at Nola	21·00	79·00
CIV. Yellow tuff at Pausilipp	9·80	90·20
CV. White tuff at Pausilipp	12·42	89·58
CVI. Tufaceous rock at Epomeo	12·78	75·22
CVII. Tuff at the crater of Monte Nuovo	41·51	78·49

The portion not decomposed by acids consisted generally of glassy felspar, and the decomposable portion consisted of hydrated silicates. In the tuff Nos. CIII to CV, its composition approximated to that of calcareous analcime. In Nos. CVI and CVII, it corresponds with hydrated oligoclase.[†]

The white tuff containing much pumicestone always overlies those of a yellow colour containing less pumicestone. The latter contain fragments of glassy felspar, augite, and hornblende, numerous patches of an argillaceous substance, fragments of trachyte, and sometimes shells.

Pumicestone tuff has originated from pumicestone by mechanical and chemical disintegration. The jasper-opal or wood-opal, and silicified trees which are sometimes imbedded in the tuff, especially in Hungary, are indicative of decompositions in which silica has been eliminated. This silica furnished material for the sheaths, etc. of infusoria, which were detected by Ehrenberg,* in several kinds of tuff between Naples and Puzzuoli, and round the lake of Laach. Other kinds of pumicestone tuff contain remains of marine shells.

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[*] Geol. Beob. p. 89.

[†] Rammelsberg.—Suppl. 4, p. 244.

Puzzolano, a kind of volcanic ash from Vesuvius was analysed by Reinhardt and Stengel, and appears to contain a portion decomposable by acids.†

The trass which occurs in considerable masses in the valleys of the Brohl and Nette resembles pumicestone tuff. According to Illgner's analysis,‡ it has a composition analagous to that of augitic lava and augitic tuff, and would appear to be a mixture of materials erupted at different times, since the pumicestone in the vicinity of the lake of Laach is always more recent than those augitic masses. It also contains fragments of clay-slate, augitic lava, basalt, etc., as well as charred trees, etc., but these plant-remains appear to have become carbonized in the wet way, and not by volcanic heat.

Steininger,§ and v. Oeynhausen consider that trass has been erupted in a muddy state from a fissure, and this view, or the one which regards it as originating from volcanic ash, is more probable than the assumption that it has been deposited from the water of the Brohl.

Schafhäutl ‖ found that the trass associated with granitic rocks in the Riese near Nördlingen differs from that of the Brohl valley, from puzzolano, and from all other kinds of volcanic tuff, and more resembles pearlstone, although it contains less silica. It also differs from pearlstone in containing a large amount of potash—6·7 per cent.—and only 2·7 per cent. of soda. It is, perhaps, decomposed granite.

There is much difficulty in classifying trachytic rocks, and there is always some uncertainty as to whether they are mixtures, or belong to different classes. Since these rocks are essentially felspathic, and since glassy felspar is the preponderating constituent, it may be inferred that when the composition of these rocks corresponds with or approximates to the oxygen quotient of glassy felspar = 0·333, and when they do not contain any large amount of lime or magnesia, they are normal trachyte.* The trachyte of the Drachenfels is the only one of this kind.

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* Monatsberichte d. Acad. d. W. zu Berlin, 1850, p. 351. Eckhard.—Poggend. Annal. lxxix, 322.

† Journ. für prakt. Chemie. xxiv, 438.

‡ Ibid. xxxiii, 21.

§ Die erloschenen Vulkane in der Eifel und am Niederrhein, 1820, p. 104.

‖ n. Jahrb. für Mineral. etc., 1849, p. 641.

A larger proportion of oligoclase would increase the oxygen quotient, possibly as high as 0·444, if the glassy felspar were replaced entirely by oligoclase. But such trachyte is unknown, the proportion of oligoclase crystals is always small, and the presence of oligoclase in the matrix can be inferred only when the amount of soda preponderates over that of potash.

The oxygen quotient is also increased by the presence of labradorite, but at the same time there would be a greater diminution of potash and increase of lime, as in No. XXVIII. There are many trachytic rocks containing labradorite in their matrices.

When the oxygen quotient is less than 0·333, it may be inferred that the rock contains free silica. However, the rocks Nos. XXII and XXVIII contain quartz, although the oxygen quotient exceeds 0·333. In the greater number of trachytic rocks the oxygen quotient is under 0·333.

When the decomposition of trachytic rocks is attended with a partial removal of bases, the oxygen quotient would be reduced, and the rock would approximate more to trachytic porphyry. But since the bleaching, and conversion of these rocks into kaolin, together with the augmentation in the amount of water, indicate the decomposed state of the rock, there is little difficulty about the classification of these rocks.

The occurrence of pearlstone and pitchstone, their low oxygen quotients, the presence of water and of bituminous substance in them, justify their classification among altered trachytic porphyry. However, there are striking anomalies in their composition, for instance, the great preponderance of lime in some.

In obsidian, the oxygen quotient varies between 0·155 and 0·521; in pumicestone it varies between 0·225 and 0·477, consequently any kind of trachyte rock may be converted into obsidian or pumicestone. These products of alteration might be classified like trachytic rocks, if they did not undergo further alteration.

The oxygen quotients of the felspathic portion of the phonolite Nos. III B to VI B, and IX B, approximate to that of normal trachyte so much that they may be regarded as trachytic rocks, mixed with zeolitic substance. If the latter were decomposed or removed, the oxygen quotient of those rocks would approximate more to that of the normal trachyte. It is, therefore, possible that phonolite may be converted into trachyte, or the reverse.*

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* Since the oxygen quotient of albite is the same as that of glassy felspar, a trachytic rock with this oxygen quotient may contain some albite, together with glassy felspar.

In several of the above-mentioned trachytic rocks, considerable alterations have taken place, but since the original composition of the rocks is not known, little can be said about the nature of the change. There are two analyses of decomposed and unaltered trachyte † that are of especial interest. At the side of a small range of trachytic hills, at Langanfjall, extending along the hot-springs in Iceland, the traces of their action are recognizable even to the top. At one place where vapour still issues, the yellowish or bluish rock is converted into a white, earthy, plastic clay. The composition of each is—

	Undecomposed.	Decomposed.
Silica	75·48	57.84
Alumina	12·97	13·71
Protoxide of iron	2·61	..
Peroxide of iron	..	8·21
Lime	1·01	0·70
Magnesia	0·03	0·14
Potash	5·43	1·24
Soda	2·72	1·94
Water	0·32	2·18
	100·57	98·96
O. Q.	0·218	0·212

Alkalies have been chiefly removed from the rock and water introduced. The preponderance of potash over soda in the unaltered rock, and the removal of five times as much potash as soda are remarkable.

The decomposed trachyte finally passes under the influence of the fumarole gases into a fatty pipe-clay, in which the iron of the rock exists in the state of pyrites crystals. These indications of decomposition are much more evident at the saalbands of the trachytic dykes.

This decomposition of trachytic rocks resembles decompositions that have been previously mentioned, with the exception that where sulphuretted water acts upon trachyte, the whole of the sulphuretted hydrogen is converted into sulphuric acid, and pyrites is not produced.

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* Volger.—Studien, p. 9.

† Bunsen.—Poggend. Annal. lxxxiii, 260.

The lavas above mentioned* show unmistakably the production of trachytic rocks with excess of silicate, from them. If an elimination of quartz from melted masses could be regarded as possible, it might be looked for in the trachytic porphyry where the free silica amounts to 28 per cent. In coarse-grained granite quartz is completely separated from the felspar and mica. Comparing the composition of the lava at St. Vico and at Monte Guardia with that of the granite Nos. XIV, XV, XXVI, and XVII, the differences are not greater than between the several lavas or granites. The granite may, like the lava, have been protruded in a melted state, but it would be difficult to account for the separation of the quartz during cooling in the one case and not in the other.

The trachytes of the Siebengebirge may, like the trachytic porphyry of Ischia and Monte Nuovo, have originated from melted masses, but their crystalline structure has been produced subsequently in the wet way. But the eruptive origin of the trachyte in the Siebenbirge is inconsistent with the fact that the strata of slate adjoining are not anywhere dislocated, while the trachyte at Zannone has elevated the Apennine limestone and tilted the strata.†

At some future time the trachyte rocks of Ischia, etc., may become surrounded with sedimentary rocks in the same manner as those of the Siebengebirge, and it may be assumed that the trachytic rocks in this latter district were once islands round which deposition has taken place. This view does not indeed agree with the occurrence of grauwacke fragments imbedded in the trachyte of the Siebengebirge, which are more than usually porous and vesicular. Altogether there remains much to be cleared up with regard to the origin of trachytic rocks, especially those which have not caused any disturbance of the sedimentary rocks adjoining them, and which are not associated with trachytic lava streams, or other indications of volcanic action.

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* See ante, p. 379.

† Abich.—Geol. Beob. p. 18.

CHAPTER LIX.

GRANITIC ROCKS.

THE constituents of these rocks are—orthoclase, either white, yellowish, or blueish, very rarely pinkish, the crystals being irregular, or more rarely regular, sometimes with smooth faces, and even four inches long; quartz, as greyish-white granules, more rarely as granular masses, and sometimes as irregular crystals, imbedded in the felspar; white mica, as irregular laminæ, sometimes also as rhombic plates, two or three inches in diameter; black mica, generally with a brownish tinge, very rarely greenish, sometimes very large and regularly crystallized, and frequently blended regularly with the white mica; oligoclase, either snow-white or with a yellow, green, or grey tinge, generally as irregular crystals, and often regularly blended with orthoclase. The oligoclase is, however, of subsequent production, because it almost always surrounds the orthoclase as a crust.

The accessory constituents of granite are—hornblende, garnet, orthite, titanite, apatite, and iron pyrites. Granite is generally coarse grained. Felspar and quartz are the chief constituents, and those that are most largely developed. Sometimes one and sometimes the other preponderates, both in size and number of crystals. Oligoclase generally occurs as smaller crystals and in less quantity than orthoclase.

G. Rose[*] distinguishes several varieties of granite as occurring in Eastern Germany. He gives the name of granitite to a rock consisting of felspar, oligoclase, quartz, and magnesian-mica, which constitutes the principal mass of the Riesen, Iser, and Brocken ranges of mountains, and always appears to be of later date than granite, &c. L. Hausmann[†] differs from him with regard to the granitic rocks in the Harz mountains.

The granite of the Ballon, the central and highest part of the Vosges, contains, besides orthoclase, a species of felspar, which

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[*] Zeitschr. d. deutschen geol. Gesellschaft, i, 352.

[†] Jahrb. für Mineral. etc. 1852, p. 972.

Delesse* calls andesine, one species of mica and rather much hornblende. As accessory constituents there are titanite, zircon, ripidolite, more rarely iron pyrites, titaniferous magnetic oxide of iron, scaly red oxide of iron, heavy spar and epidote. In the fissures there are carbonates of lime and iron.

The analyses from I to XXI are by Delesse.

	I.	II.	III.	IV.	V.
Silica	70·8	64·91	64·16	67·3	64·8
Alumina	15·3	19·16	19·16	16·1	20·0
Peroxide of iron		trace	trace	1·9	
Lime	0·5	0·78	0·56	0·6	1·1
Magnesia	12·4	0·65	0·55	13·3	
Potash		11·07	14.97†		12·7
Soda		2·49			
Loss by ignition	1·0	0·30	0·60	0·8	1·4
	100·0	99·36	100·00	100·0	100·0

I. Granite, of Plombières.

II. Large white felspar crystals from this granite.

III. Greyish-white felspar, from the same granite, slightly decomposed.

IV. Granite from the foot of the Drumont, close to the transition slate.

The slate at its junction with the granite consists of—

Silica	59·23	100·00
Alumina and protoxide of iron	28·50	
Lime	0·90	
Magnesia and alkalies	8·97	
Loss by ignition	2·40	

V. Granite, of the Presse.

	VI.	VII.	VIII.	IX.	X.
Silica	58·55	63·3	64·00	63·8	46·83
Alumina	25·26	26.2	20·55	18·7	30·33
Peroxide of iron	0·30				
Lime	5·03	1·8	0·68	2 3	9·55
Magnesia	1·30	11·8			6·86
Potash	1·50		13·59	13·8	0·81
Soda	6·44				3·57
Loss by ignition	0·91	2·9	1·28	1·4	1·99
	99·29	100·00	100·00	100·0	99·94

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* Ann. des Mines. (5,) iii, 309.

† Estimated from the deficiency.

VI. Felspar, from an erratic block from La Presse.

This mineral is crystalline, of a greenish colour, translucent, and marked with striæ.

VII. Granite, of Sainte Marie-en-Chamois, Haute-Saône.

VIII. Reddish-white felspar from this granite.

IX. Granite, of St. Bresson, very much decomposed.

X. Aphanite, with which this granite is in contact.

This rock is dark green, containing very minute fibrous laminæ, resembling hornblende, here and there iron pyrites, and very fine veins of epidote; on the whole it is homogeneous and appears to consist of a granular felspathic mass in which the presence of felspar is indicated by very delicate streaks. Where this rock traverses the granite, the texture of the latter is changed. The aphanite contains, at the point of junction, 46·47 per cent. of silica, and only 7·57 per cent. of lime. The decomposed state of these rocks is due to the easier access of water at the junction.

The granite of the Vosges is fine grained, often gneissoid, and contains quartz, orthoclase, probably oligoclase, magnesian-mica, and light-coloured potash-mica, less abundantly than the other. The orthoclase and quartz preponderate considerably.

It also contains garnet, corderite, pinite, chlorite, hornblende, fibrolite, graphite, and crystallized carbonate of lime. Iron pyrites and magnetic oxide of iron are unfrequent. The minerals of the Ballon granite occur with some others in cavities. The Vosges granite is traversed by numerous veins of granite bearing tourmaline, and sometimes metalliferous minerals.

This granite forms much smaller mountains than that of the Ballon which they surround. It is also covered by sedimentary rocks, and often passes imperceptibly into them. Delesse regards this granite as older than that of the Ballon, which traverses it at many places, and is inclined to regard the Vosges granite as a metamorphic rock.

With regard to the conversion of clay-slate and grauwacke into granite, gneiss, etc., it may be mentioned that the clay-slate, No. V,* contains about as much alkalies as the granites Nos. XI, XII, and XIII, but much more alumina, and much less silica than granite. But the sum of both constituents is the same in both the granite and clay-slate. Consequently, if granite were produced from such clay-slate, one-half of the alumina must have been eliminated, so that the amount of silica was increased to about the same as in granite. Such an elimination of alumina from clay-slate has been shown to take place;* but there are also varieties of clay-slate that correspond so closely with granite in composition, that this metamorphosis may be supposed to take place without any abstraction or addition of constituents, and merely by the crystallization of the clay-slate substance.

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* See ante, p. 122.

	XI.	XII.	XIII.	XIV.	XV.	XVI.
Silica	76·3	73·8	72·0	64·66	66·08	70·0
Alumina	12·8	15·8	15·33	19·58	18·70	17·3
Peroxide of iron ..	1·5		0·4	trace	trace	
Sesquioxide of manganese	..	trace	trace	..	..	..
Lime	0·8	0·9	0·98	0·70	0·93	0·6
Magnesia	trace	0·9	0·60	15·18	0·45	..
Potash	8·6	7·8	7·70		9·11	..
Soda			2·00		3·77	..
Loss by ignition ..		0·8	0·40	0·58	..	..
	100·00	100·0	99·41	100·70	99·04	..

XI. Leptinite, of Mehachamp.

XII. Granite, of the Feignes de Volognes.

XIII. Leptinite, close to the junction with Ballon granite, containing

Silica	64·8
Alumina and peroxide of iron	21·1
Lime	0·7

XIV. Greyish-white felspar from Wildenstein.

XV. White laminar felspar from Remiremont.

The following granites were not completely analysed:—

XVI. Gneiss, of Pont des Fées, near Remiremont.

	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.
Silica	75·4	73·3	70·4	67·3	66·7	74·25
Alumina	12·7	10 4	16·6	16·2	..	11·58
Peroxide of iron ..		1·6			1·8	2·41
Lime	0·6	0·7	0·6	1·9	0·9	1·08
Magnesia	..	..	..	0·6	..	10·01
Potash	..	..	..	..	..	
Soda	..	..	..	..	..	
Water	..	..	..	..	..	0·67
	..	..	..	..	..	100·00

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* See ante, p. 351.

XVII. Leptinite, of Docelles.

XVIII. Leptinite, in the neighbourhood of Ranfaing.

XIX. Leptinite, at the centre of the left shore of the Xenois lake.

XX. Granite, of the Vallée des Truches, near Rochesson.

XXI. Granite, of Couchelat, near Rochesson.

XXII. Protogyn, at the summit of Mont Blanc.

The principal constituents of this rock are quartz, orthoclase, oligoclase, very ferruginous mica, and a variety of talc, which distinguishes it from granite. It appears to pass gradually into sedimentary rocks, and therefore may be of metamorphic origin.*

	XXIII.	XXIV.	XXV.	XXVI.
Silica	73·13	71·20	76·02	69·31
Alumina	12·49	12·81	12·71	16·40
Protoxide of iron	2·58	4·54	1·25	4·30
" manganese	0·57	0·39	0·31	0·03
Lime	2·40	2·02	1·20	3·06
Magnesia	0·27	0·35	0·14	0·83
Potash	4·13	4·76	4·90	2·87
Soda	2·61	2·86	2·44	3·29
Water	0·53	0·43	0·48	0·84
	98·71	99·36	99·45	100·93

Granite, of the Riesengebirge.

XXIII. Granite, of Strigau.

Granular, consisting of felspar, quartz, very little oligoclase, and magnesian-mica. Felspar preponderates.

XXIV. Granite, from a vein traversing the above.

Very fine-grained and hard, consisting of a very intimate mixture of felspar, quartz, a little oligoclase, and magnesian-mica.

Both these rocks have a close resemblance, and differ only in the amounts of silica and protoxide of iron.

XXV. Granite, of the Lesser Sturmhaube.

This is a very fine-grained intimate mixture of felspar, oligoclase, and quartz, with a few black spots, probably hornblende. There does not seem to be any mica.

Granite, of the Central Carpathians.

XXVI. Granite, of Meerauge, in the Fischeel valley, on the north side of the Tatra.

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* Delesse—N. Jahrb. für Mineral. etc., 1849, p. 360.

A coarse-grained mixture of felspar and oligoclase, in about equal amounts, quartz, magnesian-mica as small laminæ, and potash-mica in smaller proportion.

	XXVII.	XXVIII.	XXXI.	XXX.
Silica	68·38	71·46	71·93	73·41
Alumina	17·87	15·57	12·89	14·87
Protoxide of iron	2·40	1·81	5·56	1·73
„ manganese	0·85	0·09	0·10	0·20
Lime	3·12	1·48	1·81	1·79
Magnesia	0·85	0·58	0·47	0·34
Potash	2·99	6·39	4·88	4·33
Soda	3·58	2·03	1·86	2·58
Water	0·80	0·76	0·49	0·57
	100·84	100·12	99 99	99·82

XXVII. Granite, of the Kohlback valley, at the eastern part of southern side of the Tatra mountains.

A rather coarse-grained, though uniform, mixture of felspar, of different sizes, with oligoclase and quartz, which is often imbedded in the felspar. Magnesian and potash-mica are present in rather considerable and about equal quantity.

XXVIII. Granite of the Völker valley at the middle of the south side of the Tatra.

Coarse-grained and less uniform mixture, felspar preponderating, much oligoclase, sometimes imbedded in the orthoclase, with quartz, partly as separate granules, partly as granular lumps. Potashmica is less abundant than magnesian-mica.

Granite of the Hartz.

XXIX. Granite of the Holzemmen valley above Wernigerode.

Fine-grained, very intimate mixture of felspar, quartz and mica, with but few separate felspar crystals. The brownish colour of the felspar indicates incipient decomposition; but the rock appears sound at the fracture. Quartz is situated between the felspar crystals, and magnesian-mica is not unfrequent. There is no potash mica, and little or no oligoclase.

XXX. Granite of the Plessburg, near Ilsensteins.

Both this and the previous granite are from the northern boundary of the granitic range of the Brocken. The felspar preponderates and seems much weathered; but the fracture is sound. Quartz is next to it in quantity. Magnesian-mica is scanty, oligoclase still more so, and there is not any potash-mica.

	XXXI.	XXXII.	XXXIII.
Silica	72·11	63·94	65·74
Alumina	15·60	23·71	18·28
Protoxide of iron	1·53	..	..
Peroxide of iron	..	trace	1·32
Protoxide of manganese	0·26	..	..
Lime	1·26	2 52	1·26
Magnesia	0·34	trace	0·20
Potash	5·00	2·17	9·25
Soda	2·27	7·66	4·20
Water	0·83	..	..
Oxide of tin	..	..	0·13
	99·20	100·00	100·38

XXXI. Granite of a dyke traversing porphyritic granite, near Heidelberg.

Fine-grained uniform mixture of felspar, quartz, potash-mica, and tourmaline. The felspar preponderates, the quartz is abundant, and the granules intimately blended with the felspar. The laminæ of mica are very small; the tourmaline is rather abundant, though less uniformly disseminated, and often in patches. This rock does not contain magnesian-mica or oligoclase.

The analyses XXIII to XXXI are by Streng.*

	Analysed by
XXXII. Oligoclase from the granite at Warmbrunn in the Riesengeberge	G. Rammelsberg.†
XXXIII. Granite of Prudelberg, in Bohemia	Whitney.‡

This rock consists of felspar, quartz, and mica, with some oligoclase at parts.

It is not possible to estimate, even approximatively, the proportions of the minerals in granite from the analyses; because there are generally two species of felspar, two species of mica, and quartz, and because the composition of mica varies very considerably. The utmost that can be done is to estimate the maximum amounts of both species of felspar, the minimum amounts of quartz, and the maximum and minimum amounts of magnesian-mica. The data for this purpose are the amounts of alkalies, lime, and magnesia. As a general rule lime belongs only to the felspars, magnesia only to the mica, and its amount is always small.

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* Poggend. Annal. xci, 122.

† Suppl. i, 104.

‡ Zeitschr. d. deutsch. geol. Ges. i, 361.

The maximum amount of both felspars is found by calculating from the quantities of alkalies and lime; for, since oligoclase contains one-fourth less silica than orthoclase, and since in both kinds of mica the alkalies are combined with less silica, than in orthoclase, the amount of silica, and also of the felspars, will be estimated too high. The calculated amount of silica deducted from that found by analysis, gives, therefore, the minimum amount of quartz in the granite. In proportion as orthoclase preponderates over oligoclase and mica, the nearer does the calculated amount of quartz approximate to the true value.

At first sight it is evident that the orthoclase in the granites Nos. XXII to XXXI must be calcareous, for provided there had not been any infiltration of carbonate of lime, the quantities of lime are too great to be referred to oligoclase. For instance, in No. XXIV, the amount of oligoclase would thus become 50 per cent., and that of orthoclase 4·57 per cent., a relation that is inconsistent with the mineralogical characters of this granite and with the large amount of potash it contains. Six analyses of oligoclase from granite and quartz give a nearly constant amount of lime, the average being 2·4 per cent.; but in other instances the amount of lime is nearly double, and it is still more irregular in orthoclase.

Since potash-mica contains, in common with the felspars, alkalies, alumina and silica, there are no data for estimating its amount from analyses. But referring magnesia to magnesian-mica, the maximum and minimum amounts of this constituent may be estimated. In magnesian-mica from granite, the maximum amount of magnesia is 25·39, and the minimum 10·27 per cent.

Calculating in this way from the analyses of granite, the maximum and minimum amounts of the constituent minerals, we obtain the following results:—

	XIII.	XXIII.	XXIV.	XXV.	XXVI.
Felspar—					
Maximum	72·65	69·69	72·05	61·57	74·14
Quartz—					
Minimum	23·51	25·75	22·37	34·53	18·51
Magnesian-mica—					
Maximum	5·84	2·63	3·41	1·36	8·08
Minimum	2·36	1·06	1·38	0·56	3·27
Alumina—					
Difference	+ 1·56	—0·68	—0·77	+ 1·17	+ 2·28

	XXVII.	XXVIII.	XXIX.	XXX.	XXXI.
Felspar—					
Maximum	77·86	69·16	62·25	64·86	61·35
Quartz—					
Minimum	15·05	25·05	29·91	29·45	30·78
Magnesian-mica—					
Maximum	8·28	5·65	4·57	3·31	3·34
Minimum	3·35	2·28	1·85	1·34	1·34
Alumina—					
Difference	+ 3·00	+ 2·67	+ 1·21	+ 2·67	+ 4·11

The numbers in the bottom line indicate the difference between the calculated and actual amounts of alumina, according as the latter is greater or less than the former.

The result of this calculation corresponds perfectly with the mineralogical descriptions that, in the above granites, felspar preponderates, that quartz is next in amount, and that the amount of magnesian-mica is very small. The large amounts of quartz in Nos. XXV and XXXI are also indicated in both cases.

Some conclusion may be drawn from the analyses as to whether the proportion of oligoclase is considerable or not. A large amount of lime and the preponderance of soda are safe indications of the presence of oligoclase. According to previous analyses, soda preponderates over potash in oligoclase, and in orthoclase the contrary relation prevails. In Nos. XXVI and XXVII, therefore, the proportion of oligoclase must be large, and this agrees with the mineralogical characters of these rocks. In the other analyses soda appears in less amount than potash, and the mineralogical characters of Nos. XXIII, XXIV, XXIX, XXX, and XXXI, agree with these indications. In Nos. XXV and XXVIII, however, these characters do not agree with the results of analysis.

As regards magnesian-mica there is a close correspondence between the results of analysis and the mineralogical characters of the granites Nos. XXIII, XXV, XXVI, XXVII, and XXIX. In No. XXV there is not any magnesian-mica. In Nos. XXVI and XXVII the amount of magnesian-mica is largest. But in Nos. XXIV, XXVIII, XXX, and XXXI, there is not any correspondence between the results of calculation and the mineralogical characters.

The generality of magnesian-mica contains a large amount of iron, to the extent of 22 per cent.; but in the analyses, Nos. XXIV and XXIX the indicated amounts of protoxide of iron exceeds the maximum of magnesian-mica. In Nos. XXIII, XXV, XXVI, XXX, and XXXI, only a portion of the protoxide of iron can be assigned to the mica. It is true that potash-mica sometimes contains much iron; but that is seldom, and it is probable that the iron indicated by these analyses belongs to other minerals. Orthoclase and oligoclase from granite do not contain much, if any, protoxide of iron, and the peroxide of iron found in some kinds of orthoclase, to the extent of 1·75 per cent., chiefly represents hydrated peroxide of iron between the cleavage surfaces. The iron in granite may safely be inferred to have the same origin for the most part. These remarks also apply to the occurrence of manganese in granite.

Since the maximum and minimum amounts of magnesian-mica may be estimated with tolerable certainty, the results obtained may serve for estimating the amounts of potash-mica. Among the constituent minerals of granite, mica is more easily recognizable than any of the others, and the great difference between the colour of magnesian and potash-mica admits of their relative proportions being estimated with equal certainty.

Potash-mica contains, with the exception of that of Abborforss, more alumina in proportion to silica than orthoclase; in magnesian-mica the reverse relation generally obtains. In calculating the maximum amount of felspar, the whole quantity of alkalies is referred to felspar, and the amount of alumina is calculated from these data, consequently the estimated amount of this earth must exceed the calculated amount in proportion as potash-mica preponderates. When, on the other hand, magnesian-mica preponderates over potash-mica, and if the proportion of alumina to silica in it is less than in orthoclase, the estimated amount of alumina would be less than the calculated amount in proportion to the amount of magnesian-mica in the granite.

In most of the analyses, Nos. XIII, XXV-XXXI, the estimated amount of alumina is greater than the calculated amount. Hence, it may be inferred, that these granites contain minerals in which the amount of alumina is larger than in orthoclase. In Nos. XXIII and XXIV, on the contrary, the estimated amount of alumina is less than the calculated amount; but the differences are too small to admit of any conclusions being drawn with safety. Moreover, it must be remembered that in both these granites there is not any potash-mica, but magnesian-mica, which reduces the amount of alumina.

Since the amounts of both kinds of mica are but small, and since the amounts of alumina they contain vary in opposite directions, it may happen that a proportion similar to that in orthoclase may result from their mixture, so that the differences in the amounts of alumina are not entirely due to mica.

The presence of water in the granites analysed indicates that some portion of the felspar has been converted into kaolin; 0·84 per cent. of water corresponds to 4·6 per cent. of kaolin; and in this product of alteration the quantity of alumina is much greater in proportion to silica than it is in the felspars, and it is probably owing to this circumstance chiefly that the estimated amount of alumina is greater than the calculated amount.

B.—FELSPAR-PORPHYRY.

This rock contains the same minerals as the variety of granite called granitite, namely, orthoclase, oligoclase, quartz, and magnesian-mica, which are imbedded in a compact matrix. Although it cannot be determined what are constituent minerals of this matrix, it is probably a very intimate mixture of the same minerals that are imbedded in it as large crystals.[†]

In felspar-porphyry, as in granite, orthoclase is present in largest amount, and mica in the least, or is quite wanting. Sometimes oligoclase also is wanting. Among the accessory constituents are corderite converted into pinite; garnet, orthite, and iron pyrites.

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[*] G. Rose.—Op. cit. p. 373.

[†] See ante, p. 50.

	I.	II.	III.	IV.	V.
Silica	70·50	68·56	70·85	76·29	76·49
Alumina	13·50	15·30	14·12	13·80	13·25
Peroxide of iron	5·50	4·25	2·72	0·72	0·88
Lime	0·25	0·50	1·62	..	..
Magnesia	0·40	0·20	..	..	..
Potash	5·50	7·50	3·57	2·43	3·14
Soda	3·55	2·62	5·23	5·39	4·02
Chlorine	0·10	..	..	..	..
Water	0·77	..	0·65	0·82	..
Loss by ignition	..	..	..	..	1·17
	100·07	98·93	98·76	99·45	98·95

Analysed by

I. Porphyry, at Kreuznach Schweizer.*

The prevailing colour of the matrix is red, passing into grey and brown. It contains a quantity of small crystals of felspar and quartz, sometimes with magnesian-mica.

II. Porphyry, of a dyke near Freiburg Kersten.†

The matrix is greyish pink, with quartz crystals the size of a buck-wheat, and patches of coarse felspar imbedded in it. This rock is but little affected by exposure to the atmosphere, but near lodes it appears greenish, and contains some ferruginous silicate of alumina and kaolin. The quartz was separated as much as possible from the specimen analysed.

III. Porphyry, at Sandfelsen, near Halle on the Saale } E. Wolff.

In the grey, or blueish-grey matrix consisting chiefly of potash and soda felspar, there are small granules of quartz, often with definite crystal form; numerous small black specks, apparently consisting partly of a micaceous mineral, and partly of fluorspar, which not unfrequently appears as small crystalline specks. The rock gradually bleaches by exposure, the felspar loses its lustre, and the whole mass crumbles to a sandy mass resembling kaolin.

IV. Porphyry, occurring near the above, and probably originating from it.

This rock is bleached and has a schistose structure, so that it can be separated into plates, between which a substance resembling kaolin is deposited. The felspar has also become colourless, and, like the matrix, appears corroded at some parts. The rock does not contain either mica or fluorspar.

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* Poggend. Annal. li, 287.

† Ibid. lix, 129.

If this rock has originated from the alteration of the former, the amount of silica has been relatively augmented in consequence of the abstraction of bases. The presence of kaolin between the plates account for the increase of the silica and diminution of the alumina. The bleaching is due to the removal of peroxide of iron chiefly. Since there is no fluorspar in this rock, the total absence of lime is probably due to the removal of that mineral. It is an anomalous feature of this alteration that part of the potash has been removed, but none of the soda.

V. Yellowish porphyry, at the same place as the two former.

This also presents a schistose structure, and at the joints there is a substance like kaolin, of the same dirty yellow colour as that in the other rock.

This rock closely resembles the former, both chemically and physically, and can only be regarded as the product of porphyry that has undergone alteration. The only difference between this rock and the previous one is, that more soda than potash has been removed. In cases like these where the presence of weathered potash and soda felspar has been recognised, the explanation of this different kind of alteration might be sought in the preponderating decomposition of one or other of these felspars. Decomposed and sound felspar of the same species is not unfrequently associated, and it is easily conceivable that different species may be unequally decomposed, so that the rock would be sometimes deprived of potash, and sometimes of soda.

	VI.	VII.	VIII.	IX.
Silica	75·62	71·7	77·5	57·60
Alumina	10·01	15·0	12·9	25·00
Peroxide of iron	3·65	2·9	2·5	
Lime	0·47	0·4	0·4	3·23
Magnesia	..	8·8		
Potash	4·16		5·9	9·92
Soda	3·84			
Water	1·10	..	..	..
Loss by ignition	..	..	..	4·25
	98·85	98·8	99·2	100·00

VI. Red porphyry at Tansberg, near Diemitz E. Wolff.*

This rock contains felspar, sometimes as cruciform twin crystals, also quartz, more frequently than in other varieties, but little magnesian-mica, and no fluorspar. The decomposition of this rock appears to progress more slowly, for layers of kaolin do not occur near it, and the red colour has been retained throughout. It is only the felspar imbedded in the mass that is sometimes rather bleached or converted into kaolin with retention of its form.

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* Journ. für prakt. Chemie. xxxiv, 192.

In these porphyries the products of decomposition are various. Chrom-ochre occurs in the highly decomposed porphyry at Sandfelsen, either at the joints, or as thin threads traversing the rock. It is a mixture of from 25·55 to 26·42 per cent., of a substance insoluble in sulphuric acid, and consisting of 94·16 per cent. silica, and 4·49 per cent. alumina, oxides of iron and chromium, with from 73·58 to 74·45 per cent. of kaolin, containing 46·11 per cent. of silica, and 4·28 per cent. oxide of chromium. The masses called "knollenstones," also occur in fissures in the porphyry which is much decomposed near these fissures. The "knollenstones" are white compact masses with numerous small shining granules of quartz. According to six analyses, they consist of from 97·01 to 99·11 per cent. silica, and 0·83 to 1·81 per cent. alumina, peroxide of iron sometimes with sesquioxide of manganese, and volatile substance.

Chrom-ochre appears as a porphyritic mass that has been converted into kaolin and silica. The "knollenstones" contain only the latter of these products of decomposition, together with minute quantities of bases, and appear to be rather deposits from water than the residual products of the alteration of the rock.

	Analysed by
VII. Porphyry of Montreuillon	Delesse.*

The matrix of this rock is greenish-white, and contains quartz crystals the size of peas, laminæ of felspar, and dark-green mica.

VIII. Porphyry of Saulieu	Delesse.*

The matrix is brownish-red, and contains angular fragments of quartz, laminæ of felspar, and sometimes dark-green mica.

Both this and the previous rock contain a small quantity of carbonates.

IX. Porphyry of Lessines, in Belgium	Delesse.†

The matrix is of a dark greyish-green colour, owing to the presence of a soft hydrated silicate of magnesia and iron, which Delesse regards as a pseudomorphous chlorite; it sometimes contains quartz and hornblende. The presence of the hydrated silicate, and of carbonate of lime and iron, iron pyrites, copper pyrites, and carbonate of copper in one place, indicates that decomposition has taken place. Delesse ascribes the small amount of silica in this porphyry to the presence of chlorite and carbonates.

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* n. Jahrb. für Min. etc. 1850, p. 186.

† n. Jahrb. für Min. etc. 1851, p. 160.

	X.	XI.	XII.	XIII.
Silica	63·70	62·17	58·92	77·99
Alumina	22·64	14·60	22·49	15·00
Peroxide of iron	0·53	7·80	0·75	
Lime	1·44	3·30	5·53	1·00
Magnesia	1·20	5·00	1·87	
Potash	2·81	2·04	0·93	6·00
Soda	6·15	4·10	6·93	
Water	..	0·58	1 64	0·01
Loss by ignition	1·22	..	..	..
	99·69	99·59	99·06	100·00

Analysed by

X. Oligoclase from the porphyry of Quenast, in Belgium } Delesse.*
XI. Red antique porphyry from Egypt }

This rock consists almost entirely of a felspathic matrix, with imbedded crystals of felspar, hornblende, specular oxide of iron and some magnetic oxide. Quartz occurs in it only as small irregular veins. It effervesces slightly with acids.

XII. Oligoclase from the above porphyry } Delesse.†
XIII. Porphyry at Rennas }

This rock contains small crystals of orthoclase, oligoclase, and hornblende, together with numerous granules of steel-grey oxide of iron. It barely effervesces with acids.

Wolff and Hochmuth endeavoured to ascertain by calculation from the results of analyses the constituent minerals of porphyry. They came to the conclusion that the matrix contained small quantities of alumina, peroxide of iron, sesquioxide of manganese, etc. It was also assumed that albite is associated with orthoclase in porphyry; but G. Rose‡ considers that this is never the case, and that oligoclase alone is associated with orthoclase. Delesse is of opinion that andesine sometimes takes the place of oligoclase.

Analysis shows that lime is an essential constituent of oligoclase, and the varieties, Nos. X and XII, contain a large amount; but the porphyry, Nos. IV and V, and that of Gottesgab, in

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* Ann. des. Mines. 4, xviii, 103.

† Ann. de Chim. et de Phys. 3, xxx, 81.

‡ Poggend. Annal. lxvi, 109.

Silesia,* do not contain any lime, and the other varieties contain but very little. However, since the porphyries, Nos. IV and V, are in a decomposed state, and since Delesse has ascertained the presence of carbonate of lime in several varieties of porphyry, we are justified in inferring from the small amount or absence of lime in porphyry that it is, to some extent, altered. It appears, therefore, that the felspar in felspathic porphyry loses its lime much more readily than that in fine-grained granite.

In the porphyry Nos. I, II, and VI, potash preponderates over soda, in the other varieties soda preponderates, and this is likewise the case with the porphyry of the Donnersberg and of Gottesgab. In the former instances, therefore, it may be inferred that orthoclase preponderates, and in the latter, oligoclase. However, comparing No. III with Nos. IV and V, it appears that when alteration commences, the relative proportion of the alkalies may be changed.

These circumstances combined, tend to show that in the case of porphyry, the relative proportion of the felspars cannot be inferred with nearly so much certainty, as is the case of the fine-grained granite. Calculations made in the same manner as for granite, give the following results :—

	I.	II.	III.	IV.	V.
Felspar— Maximum	65·75	72·18	81·39	60·70	53·22
Quartz— Minimum	26·33	20·39	15·32	34·92	40·45
Alumina— Difference	+ 1·22	+ 1·91	—1·32	+ 2·30	+ 3·23

	VI.	VIII.†	IX.†	XI.
Felspar— Maximum	62·24	38·08	49·11	78·31
Quartz— Minimum	33·55	55·19	40·61	8·28
Alumina— Difference	—1·69	+ 4·30	+ 5·42	– 0·38

These results indicate very irregular proportions in the quantities of felspar and of quartz, for though these values are merely extremes, they are, nevertheless, approximatively comparable, since the values for felspar are calculated according to the composition of orthoclase.

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* See ante, p. 138. † Ibid.

In No. I, which contains recognizable magnesian-mica, its maximum and minimum amounts are 3·89 and 1·58. Assuming that Nos. IV and V have really originated from III, the considerable diminution of the felspar and the considerable augmentation of the uncombined silica becomes much more evident than by the comparison of the analytical results. While in No. III, the calculated amount of alumina is 1·32 per cent. less than the estimated amount in Nos. IV and V, on the contrary, the former is 2·3 and 3·23 per cent. more than the latter, in consequence of the partial removal of alkalies, and of the total removal of lime, and the relative augmentation of the alumina. Such rocks for which calculation gives an excess of alumina, are mixtures of felspar, quartz, and silicates of alumina.

In Nos. VIII and IX the quantities of silicate of alumina are still greater. Since these rocks have a very sound appearance, it may be inferred either that these silicates were produced together with the felspar and quartz, or that alteration has taken place. Whatever may have been the origin of these rocks, it cannot be supposed that the alkalies, lime, and alumina, were always in such quantitative proportions as would be requisite for the production of orthoclase and oligoclase. Considering that in both species of felspar the oxygen ratio of alkalies and lime to alumina, is the same, no circumstance can be imagined by which an excess of one or other base could have entered into the composition of these minerals, provided these bases were all converted into othoclase and oligoclase. Consequently, in those instances, where an excess of silicate of alumina did not give rise to the production of other minerals, for example mica, there can be no doubt as to the separation of silicate of alumina. On the other hand, considering that there are anhydrous silicates of alumina, such as andulusite, chiastolite, and cyanite, that only occur crystallized, and which crystallize from clay-slate, it seems remarkable that these minerals are not met with in felspathic porphyry, where the conditions for crystallization existed to the greatest extent.

Lime, the essential constituent of oligoclase, is also frequently present in orthoclase, but in the porphyry, No. VIII, there is but a small amount of lime, and there is not any in No. IX. If this latter rock were quite unaltered, it would be inconceivable that these felspars, especially oligoclase, could have been produced.

Therefore, the lime has probably been removed from these rocks, as in the case of No. III, either wholly so for the most part, and in that case an excess of silicate of alumina would necessarily be found in it.

Hence, it will be evident how difficult it is, in many instances, to decide as to the presence or absence of some constituents of crystalline rocks, even when mineralogical and chemical examinations are made. The difficulty amounts to impossibility where no attention is paid to the fact that all rocks are continually subject to alteration, and that their sound appearance is not any indication that alteration has not taken place. When the presence or absence of substances cannot be ascertained mineralogically, it is only by means of chemical analysis that any conclusions can be arrived at.

The red colour of porphyry is undoubtedly due to the sometimes considerable amount of iron in this rock; for ferruginous minerals, such as mica, hornblende, proto-silicates of iron, etc. occur in it but seldom, and in small proportion. This is evident also from the circumstance already mentioned, that the decomposition of the rock is attended with bleaching and removal of the greater part of the iron. Probably a portion of the water in porphyry belongs to hydrated peroxide of iron present in it.

C.—GRANULITE, LEPTINITE.

These rocks consist essentially of orthoclase, quartz, and garnet. The following analyses seem to indicate the presence of another species of felspar containing soda. The accessory constituents comprise mica, cyanite, and hornblende.

	I.	II.	III.	IV.
Silica	81·77	73·04	73·72	53·66
Alumina	7·02	8·23	11·91	12·84
Protoxide of iron	2·74	6·27	5·08	2·79
Peroxide of iron	..	1·35	1·38	7·05
Protoxide of manganese	1·44	2·32	1·83	trace
Lime	0·97	1·18	2·21	5·02
Magnesia	..	..	..	4·27
Potash	3·92	7·11	1·50	3·89
Soda	2·04	..	2·37	7·02
Phosphoric acid	..	trace	trace	3·47
	99·90	99·50	100·00	100·01

Hydrochloric acid digested (for a long time) with the powdered rocks extracted from them.

	I A.	II A.	III A.	IV A.
Alumina	0·009	0·012	0·087	4·773
Protoxide of iron	0·134	..	..	..
Peroxide of iron	..	0·600	1·275	3·129
Protoxide of manganese	0·071	0·055	0·859	..
Lime	0·041	0·036	0·890	3·101
Magnesia	..	..	..	2·622
Phosphoric acid	..	..	..	trace
	0·255	0·703	3·111	13·625

Analysed by

I. Granulite, from the Teufelsmauer, a dyke from three to five fathoms wide, near Krems, extending to the Danube } E. Hornig.*

This rock contains at many places numerous crystals of black tourmaline; but there was not any in the specimen analysed.

II. Granulite, between Aggsbach and Gurhof.

Greenish-white, very fine grained; containing a number of small red specks of garnet, and a few crystals of blue cyanite.

III. Granulite, near Unter-Bergen, on the south bank of the Danube.

At one part this rock is covered with a layer of clay and sand, the products of its disintegration by weathering. It is white, and fine-grained, containing a number of red and blue specks.

These rocks became ochre-yellow by exposure.

IV. Granulite, near Strass, north-east of Krems.

This rock passes into gneiss containing hornblende. It is either white or dirty green, and sometimes contains fragments of quartz and felspar.

It is difficult to calculate from the analyses Nos. II and III the maximum of felspar, because it is not known whether the lime in the rocks to which they refer belongs to garnet or not. Nos. I and II decidedly contain a soda-felspar besides orthoclase, so that a portion of the lime in this rock belongs to it; but No. II seems to contain only orthoclase. Hornig calculates the amount of free silica in these rocks as follows:—

I. 58·96 per cent.
II. 43·05 „
III. 44·83 „
IV. 0·49 „

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* Sitzungsbericht der mathemat. naturwiss. Classe d. Acad. d. W. zü Wien VII. S. 583.

but these results must be somewhat uncertain since orthoclase and oligoclase do not contain the same silicate of alumina. The iron dissolved from Nos. I, II, and III by hydrochloric acid probably corresponds to hydrated peroxide or magnetic oxide of iron, and the considerable amount of iron in the portions of Nos. II and III, undecomposable by hydrochloric acid, probably originates from garnet.

The small amount of silica in No. IV, the presence of quartz in it, the considerable amount of alkalies, protoxide of iron, lime, and magnesia, and the large portion that is decomposed by hydrochloric acid, are all so little in accordance with the composition of granitic rock that this one cannot be regarded as one of this class. It probably contains hornblende.

The comparative examination of the quartzose rocks leads to the following conclusions:—

The composition of the granitic rocks Nos. XIII, XXII, XXVI, XXV, XXVIII, XXIX, XXX, and XXXI approximates closely, as regards the amount of silica and alumina, to the trachytic porphyry in the Ponzo Islands and to the trachytic rocks in Iceland. There is also a resemblance to XXXVI and XXXVII, except that in these there is rather more silica and less alumina than in granite. The chief difference between these granites and trachytic rocks consists merely in the relative proportions of potash and soda. As regards the total amount of alkalies there is a close correspondence.

	Mean.	Maximum.	Minimum.
Granite	7·59	9·70	6·74
Trachytic rocks	7·39	10·67	5·94

The other constituents, oxide of iron, lime, and magnesia, are of subordinate importance, both in granite and trachyte.

Both the orthoclase in garnet, and the glassy felspar in trachyte contain more potash than soda, but the preponderance of potash is greatest in othoclase. Consequently, the production of orthoclase or granite from material containing a large proportion of potash, and the presence of a larger amount of potash and less soda in orthoclase than in the results of the analyses, may be readily understood; for oligoclase, which is rarely wanting in granite, contains more soda than potash.

Since glassy felspar, like orthoclase, contains more potash than soda, its production, or that of a trachytic rock, from material containing more soda than potash, cannot be accounted for easily. However, considering that the preponderance of potash is less in glassy felspar than in orthoclase, it may be assumed that, when soda preponderated, there would be a greater tendency to the production of the felspar containing least potash. Moreover, those trachytic rocks in which soda preponderates, contain, besides glassy felspar, some kind of soda felspar.

This view of the matter might be sufficient if it could be regarded as universally the case that from material of the same composition orthoclase and oligoclase are produced when potash preponderates, and that glassy felspar and oligoclase are produced when soda preponderates. But in the granite Nos. XXVI and XXVII soda preponderates, and in the trachytic rocks, Nos. XXI, XXXV, and XXXVIII, potash preponderates.

The case becomes still more complicated when the granite Nos. XXVI and XXVII are compared with the trachytic porphyry-lava No. XVIII. These three rocks are very like in composition; soda preponderates in all, and the total amounts of alkalies are much the same. If the production of granite by the solidification of a melted mass were possible, we might expect the above lava to present the character of granite like those which agree with it in composition. The trachytic rocks of Iceland, like those in the Ponza Islands, are mostly amorphous, and only in a few instances present indications of imbedded felspathic minerals. If in the course of time these rocks should become crystalline in consequence of metamorphism in the wet way, they would give rise to trachytic or granitic rocks, according as the potash or soda preponderated in the mass. The excess of silica would be eliminated and remain as quartz, as it is found in granite. The quartz crystals in trachytic-porphyry may indicate the commencement of such an alteration.

Since mica contains only a small proportion of soda, there would be a greater tendency to the production of this mineral from an amorphous mass containing a preponderance of potash than from material in which soda preponderated. However, it is striking that the granites Nos. XXVI and XXVII, in which soda preponderates, contain a large amount of mica. Therefore, in such granite, where the potash belongs principally to the orthoclase and mica, there must be a soda felspar also present, and, in fact, No. XXVI contains nearly equal proportions of oligoclase and orthoclase.

There are not enough analyses of syenite to admit of any comparison between it and granite, as regards composition. On account of the presence of hornblende the amounts of lime and magnesia are greater than in granite.

Felspar-porphyry is so intimately related to granite that they may be regarded as chemically identical. Granulite appears to be, for the most part, very quartzose granite.

The parallel between clay-slate and granite also obtains in the case of other quartzose rocks, especially felspar-porphyry. Although clay-slate generally contains less alkalies than granitic rocks the amount is sometimes* so nearly equal to that in the latter, that it is easy to conceive the conversion of clay-slate into granite or into gneiss.

Studer's† investigations have made known many facts illustrative of the intimate connection between limestone and gneiss in the Swiss Alps. The limestone in Val Pellina, which is mostly converted into white marble, often contains mica, quartz, and garnet, and then closely resembles granite in appearance. Gneiss, syenite, and marble are blended together irregularly. In the Val Varia there is a granular limestone mixed with mica and quartz, and blended with streaks of gneiss. Between this point and the Val Vedro there is another mass of limestone situated between the gneiss, like that at the Mettenberg, the Wetterhorn, and Laubstock in the Bernese Oberland. The limestone is, however, entirely converted into white marble, and alternates repeatedly with gneiss at many places.

The central portion of the Finsteraarhorn, where the Alpine granite is most abundant, presents at its northern boundary a remarkable blending of the quartzite, gneiss and limestone. Near Gasteren, above the Kumi, horizontal bands of gneiss, extending from the eastern gneiss mountains, alternate with bands of dolomitic limestone and quartzite, connected with the limestone of the Balmhorn. Below Guttannen, at the Schafteien, nests of marble mixed with quartz occur in the gneiss.

Supposing the whole of the masses of limestone between Val Vaira, Algaby, Vegia, Dever, and Crevola, to be connected together, they would appear as a fissured lenticular shaped mass, the existing central portion of which is situated horizontally, while the edges extend at all sides under the gneiss mountains, and terminate in them. Under the gneiss, which everywhere underlies the limestone, there is granite in Val Vedro, and the protrusion of this granite might be supposed to have fissured the limestone. Nevertheless, Studer found, repeatedly, that there is no connection between the formation of the valleys and the occurrence of granite or gneiss. Moreover, throughout the whole of the Alps of Tessin, the granite is so intimately blended with the gneiss that the two cannot be distinguished.

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* Sterry Hunt.—Phil. Mag. 4, vii. 233.

† Geologie der Schweiz, i. 388.

The envelopement of limestone and gneiss and the mutual penetration of both rocks prove that the formation of the outer boundary of the limestone, and perhaps its conversion into marble and dolomite, must have taken place at the same time as the production of gneiss. The dolomite like the marble, is bedded in the gneiss and also in the mica-slate at Veglia, Val Canaria, etc.

The manifold convolutions and intermixture of the limestone and slate strata at the Atels and Doldenhorn, as well as the conversion of the undermost bed into marble and dolomitic limestone, is regarded by Studer, as evidence that in this locality, as in Savoy, the limestone existed prior to the granite. Below the summit of the Jungfrau, which consist of gneissoid granite, horizontal layers extend from the limestone into the granite. These masses of limestone are partly unaltered and partly converted into white or variegated translucent limestone, or dolomitic limestone. These alterations never extend far into the mass, and near the line of contact there is calcareous slate, imbedded in the granite, that is quite unaltered. These facts induced Studer to conclude that the limestone was elevated and pushed on one side, by the protrusion of the granite in a pasty state; but at the same time there are not any indications of the granite having been melted.

The occurrence of felstone with the form of calc-spar[*] proves the possibility of carbonate of lime being displaced by felspathic substance. Volger[‡] also describes instances of the association of adular and pericline with calc-spar, at St. Gotthardt, which show that felspar, quartz and mica may be substituted for the carbonate of lime in calc-spar; consequently, it may be inferred that granite or gneiss may be produced from limestone in the same manner. In one instance he found that a ferruginous limestone containing hornblende, had been converted into a rock, consisting of felspar, chlorite, and rutile.

There is not any rock more liable to alteration by displacement than limestone, for we are acquainted with no less than twenty-eight minerals that occur pseudomorphous after calc-spar. All siliceous substances occur with the form of calc-spar. In the gorge of St. Ullrich, the dark coloured calcareous slate, containing numerous fossil remains of *halobia lommelli*, is converted into a hard hornstone, and the above-mentioned blending of the quartz, etc., with limestone, is the simplest case of the displacement of carbonate of lime by silica.

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[*] English edition, ii, 186.

[†] Studien zur Entwicklungsgeschichte der Mineralien, p. 150.

These changes have, undoubtedly, been effected in the same manner as pseudomorphs have been produced. Supposing a bed of limestone uniformly permeated by water, containing silica, during a long period, nothing is easier to conceive than that, by the removal of carbonate of lime and the substitution of silica in its place, the whole rock would ultimately be converted into a quartzose mass. If the permeation of the limestone was unequal the alteration would not be uniform, and portions of the limestone would remain more or less unaltered. This is found to be the case even with the pseudomorphous quartz after calc-spar, as at Przibram, in Bohemia. If the removal of lime exceeded the deposition of silica there would be a depression of the strata regularly or irregularly, according as the former action preponderated more or less over the latter, and in this way the various convolutions and dislocations of the strata may have been produced.

These remarks also apply to the displacement of carbonate of lime by felspathic substance, and if both changes take place together, the chief constituents of gneiss would be substituted for the limestone removed. If, therefore, gneiss may be produced from limestone by displacement, there is less reason to question the possibility of clay-slate being converted into gneiss by the mere crystallization of the mass by action of water.

By the mechanical and chemical disintegration of granite and other crystalline quartzose and felspathic rocks, they are essentially converted into clay and quartz. These products are separated by rivers, and in the ocean give rise to sandstone and augillaceous deposits.

It is only in few instances that the felspar is decomposed into silicate of alumina, with entire removal of alkaline silicates, as is shown by the analysis of suspended snbstances in rivers of clay-slate, shale, clay, and kaolin. These analyses also show that crystalline rocks may be produced from such deposits. It appears, therefore, that the whole series of sedimentary and crystalline rocks are continually undergoing alteration, the sedimentary strata again becoming crystalline rocks. The separation of the quartz seems to be absolute, since the sand could only give rise to sandstone, which by subsequent disintegration would again yield sand. However, the felspathic mass that remains in the disintegration of granitic rocks and clay-slate, or grauwacke of similar composition contains silica enough to yield quartz by partial decomposition.

CHAPTER LX.

METALLIFEROUS VEINS—LODES.

THE greater number of the metals occur combined with either oxygen or some other electro-negative element. The only exceptions are the noble metals, and the metals of the alkalies and earths. Those oxides of the heavy metals that are basic, as well as the alkalies and earths, occur in combination with silicic, carbonic, sulphuric, and phosphoric acids, as well as with the metallic acids. Lime, and more rarely yttria, are, however, the only earths that occur in combination with metallic acids.

It is a peculiar characteristic of the heavy metals, that the majority of them occur in combination with sulphur, and that those next to iron in abundance are chiefly found in this state, while compounds of the alkaline and earthy metals with sulphur, are not met with. This is evidently a consequence of the physical characters of these compounds respectively, the former being among the least soluble substances known, the latter being very soluble. Hence, if the latter were produced by the decomposition of sulphates, they would be carried away in solution.

A further geological distinction between the heavy and light metals, consists in the fact that several of the former occur native, while the latter do not. Some of the former, however, could not exist in this state. At one time it was supposed that, originally, all metals existed in an uncombined state; but, if this were the case, if the earth was once a metallic mass, it could have remained so but a short time when in contact with water and an atmosphere containing oxygen. The native metals that are found at the present day are certainly not remains of such a metallic mass, for all of them are products of reduction, the last stages of a series of alterations which the metallic compounds have undergone and are still undergoing.

Although it soon becomes evident that the first stage of this progressive alteration cannot be ascertained, it is at least certain that the silicates of the earths and alkalies, of the oxides of iron and magnanese are among the oldest constituents of the earth's crust. Consequently, the same may be supposed to be the case with the oxides of the heavy metals. But it happens that those metals which, next to iron, are the most frequent, either do not occur at all as silicates, or only very seldom. Thus, for instance, no native silicate of lead is known, and the rare silicates of copper have originated from the decomposition of other copper ores. It is only in a few cases that there is any great probability that metallic silicates are pristine substances, so far as that can be assumed, of any minerals. Such is, however, the case with the silicates of cerium, lanthanium, didymium, and chromium.

Most of the native compounds of the electro-positive metals, excepting those of iron, manganese, and zinc, have originated from sulphides. Consequently, these sulphides must be regarded as of prior date to those compounds. Some metallic compounds originate also from arsenides, antimonides, and tellurides. It has been shown already that sulphur cannot be regarded as of primitive origin, and it will now be shown that this is also the case with the sulphides. With regard to this point, as to arsenic, antimony, and tellurium, which so closely resemble sulphur, nothing certain is known.

The circumstance that metals and their compounds occur chiefly upon lodes, seems to facilitate the distinction between earlier and later mineral products. It is certain that the contents of a lode are of later date than the adjoining rock; so that, if it can be shown that these contents originate from the adjoining rock, and if it can be ascertained what compounds of the metals exist in that rock, the previously-existing minerals may be distinguished from those of later date. But the determination of this point is attended with great difficulties, and is, generally, impossible.

Traces, and even estimable quantities, of metals have been detected in the analyses of rocks, but attention is not often directed to their detection, and the whole routine of analysis does not admit of a positive inference as to the state in which such traces of metals exist in the rocks. A better result in this respect may be looked for from the analysis of minerals constituting the rocks; for, as foreign admixtures would be separated by crystallization, the nature of the metallic compounds might sometimes be ascertained more easily. Many minerals present between their planes of cleavage, visible particles of substances foreign to their composition; and the traces of metals found in the analysis of rocks may, therefore, be derived from invisible particles situated between the cleavage planes.

The very slight solubility of the metallic sulphides does not afford any probability that the sulphides in lodes existed in the adjoining rock, and were transferred directly thence into the lodes. If, on account of this character of metallic sulphides, it is inferred that they were produced in the lodes from other compounds, it must, nevertheless, not be forgotten that they occur, not only in sedimentary, but also in crystalline rocks; as, for instance, iron pyrites, copper pyrites, and molybdenum glance in granitic and syenitic rocks. But if the metallic sulphides in lodes cannot have been introduced in that state, this must, also, be the case with the sulphides occurring in crystalline rocks; and, in many cases, it is evident that they have originated in the same manner, and at the same time, both in lodes and in the adjoining rock.

The analogy between iron and manganese, on the one hand, and the other metals, might justify the placing of metallic silicates at the head of an arrangement of metallic compounds, according to their probable relative age. It is certain that the oxides, carbonates, etc., of iron and manganese in lodes, have originated from the silicates of these metals in the adjoining rocks. With regard to like compounds of other metals, a similar origin is merely conjectural, although it is rendered probable by the fact, that several other metals, such as zinc, copper, etc., do occur as silicates.

With regard to the compounds of iron and manganese, it is certain that they have not passed from the lodes into the adjoining rocks. This is not so evident in the case of other metallic compounds; but it would be very inconsistent to suppose that spathic carbonate of iron and zinc blende, which in many lodes, constitute the chief mass, have passed from the adjoining rock to the lode, and that the minerals associated with them have passed from the lode into the adjoining rock. Hence it may be more probable that the metallic compounds occurring in rocks, and in their constituent minerals, are of prior date to those in lodes, than that metallic ores have been injected or sublimed into the lodes by plutonic action.

Limiting our consideration to existing minerals, sulphides may be placed next in order of date to silicates, since the sulphides of electro-positive metals appear older than all their other compounds. Next in order come the compounds of metals with selenium, arsenic, antimony, and tellurium.

Those electro-negative metals which occur combined as acids, with bases, and constitute minerals, should, strictly, be placed before the sulphides, since it is certain that these compounds were produced simultaneously with the rocks they are imbedded in. But, as they also occur in lodes, some of them, indeed, like the arsenates, being, undoubtedly, of very recent origin; and, as no distinction can be made between the salts of metallic acids occurring in lodes, and those occurring in rocks, they have been placed after the sulphides, etc. They are, therefore, placed in two classes: the first of which comprises the salts of metallic acids imbedded in rocks; the second, those occurring in lodes. Next to these come the carbonates, phosphates, and sulphates of metallic oxides, which certainly belong to the most recent minerals.

Next in order come the chlorides, bromides, iodides, and fluorides of the metals, most of which are, undoubtedly, of the same relative date as the carbonates, phosphates, and sulphates.

Of the same date as these oxygen and haloid salts, and, in fact, of later date than these, are the metallic oxides and hydrated oxides, even the oxides of iron and manganese, for these minerals have originated from the decomposition of the carbonates of those metals.

Foremost among the metallic oxides, are oxide of zinc and titanic acid, the only metallic oxides which occur in crystalline rocks, and, consequently, are of the same date as the other minerals with which they are associated. But although, in this point of view, they are among the oldest metallic compounds, this holds good only with regard to certain localities, for they also occur in lodes and in drusy cavities. Therefore, the metallic oxides, like the salts of metallic acids, are classed in two sections.

It is particularly difficult to assign a place in this series to the native metals. From silver, downwards, to iron, it is certain that they are products of reduction. With regard to others, again, that are known only in the metallic state—gold, tellurium, platinum, palladium, iridium, osmium—there are no data for determining whether they have originated from compounds or not. So far as it is possible to ascertain, these are primitive substances. They are of the same date as the metallic oxides and salts of metallic acids imbedded in crystalline rocks. However, the native metals are divided into two classes; one comprising the noble metals, the other, those metals that undoubtedly belong to more recent productions. Between these two classes, however, there is no definite distinction to be drawn; for, while the silver, alloyed with native gold, is certainly of the same origin as the gold, the silver, associated with silver ores, is a product of reduction.

According to these views, the following series of metals and their compounds may, with regard to the above-mentioned limitations, correspond with their relative date, and represent approximatively, the order of succession in which they have been produced. But since it is especially in metalliferous lodes that chemical changes have taken place, and still go on, it is possible that certain metallic compounds may be reproduced after their constituents have undergone a long series of changes; and, that this is really the case, will be shown by several examples. There is nothing abnormal in this fact; for the most important, and, also, most frequent mineral, felspar, occurs, as one of the oldest known minerals, and also, though rarely, in drusy cavities, in the form of the most recent minerals—laumontite and analcime.

The order in which the consideration of this subject will be conducted is, after a brief statement of the localities in which the ores and their associated minerals occur, and of their composition, to describe the decompositions and alterations to which they are subject, as these are indicated by pseudomorphs.[*]

The successive order in which associated minerals have been produced in lodes and deposits of ore, is of especial importance for ascertaining their origin. The phenomena of association were first pointed out by Henckel; and their importance was shown by De Dolomieu. More recently, Fournet[†] has treated of this subject, and Weissenbach[‡] has contributed to it his valuable drawings of remarkable features of lodes. But Breithaupt[§] was the first to give a systematic view of the succession and relative date of the associated minerals constituting lodes, especially in reference to Saxony. The arrangement which he adopts is the following:—

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[*] By a comparison of what is known with regard to the genetic relations of the copper and lead ores, with the uncertainty that prevails as to other ores, it will be seen that there is good reason for making a careful examination of the pseudomorphic phenomena presented by the latter. For this purpose chemical analysis must be combined with mineralogical determinations, so that when it has been ascertained what changes have taken place, it may be possible to ascertain how they have been produced.

[†] Du caractère d'Association en Minéralogie et en Géologie.

[‡] Cotta—Gangstudien, i, 1, et seq.

[§] Die Pargenesis der Mineralien. See also Edinb. New Phil. Journal. 1852.

I. *Augite, garnet, pyrites and blende formation.*—These deposits of ore are generally considered to be beds; they do not present the structure characteristic of lodes, the minerals being confusedly mixed together. The augite appears to be the oldest member; then follow vesuvian, garnet, sulphides and arsenides, magnetic oxide of iron and oxide of tin. Quartz and calc-spar appear to be generally the most recent, and are found filling the few drusy cavities.

II. In the *titanium formation*, felspar is the oldest member; then follow titanic acid and its compounds. Quartz is generally of later date, and it is only when associated with rutile that it appears as a simultaneous and even prior mineral.

III. In the *tin and wolframite formation*, principally represented by oxide of tin and wolframite, quartz appears as the oldest member; then follow successively oxide of tin, wolframite, sometimes blende, sometimes molybdenite, sometimes pyrites, sometimes apatite, fluorite, topaz, steinmark, or chlorite, etc.; and, sometimes, several of these minerals together. It is rarely that quartz is altogether wanting, and then the initial member of the series is either beryl, wolframite, or blende; it is also very rarely that quartz appears in small crystals as the final member of the series. In most instances, oxide of tin, or wolframite, or both, are entirely wanting, especially when specular oxide of iron appears immediately succeeding quartz. Sometimes quartz is followed by mica.

IV. In the *noble quartz formation*, the initial member is always quartz, frequently as hornstone, generally attached firmly to the adjoining rock, sometimes ramifying into it. In Saxony, this formation is characterized by argentiferous mispickel always containing gold, which is generally imbedded in quartz, and is remarkable for the uniformity of its composition. Among minerals of the glance species, sulphide of antimony and the products of its decomposition preponderate, but there is a great variety of other metallic sulphides. Silver and gold appear as the youngest members, resulting from the alteration of other minerals. In Transylvania and Hungary, black tellurium not unfrequently follows quartz.

V. In the *pyritic lead and zinc formation*, there occur large masses of galena, blende, arsenical-iron-magnetic and copper pyrites. Of fifty-six localities where lodes of this kind occur, there are forty-four where quartz is the initial member of the mineral series, four where it is calamine, three where it is galena, and four where it is either blende, mispickel, iron pyrites, or molybdenite. Frequently the minerals constituting this formation are mixed together in compact masses. In the druses that sometimes occur, galena and blende are generally the oldest, and pyritic minerals more recent. The frequent fact, that the outcrop and the upper parts of lodes bear iron ores, especially brown and red iron ore, while, at greater depths, they bear ores of lead, copper, cobalt, nickel, and silver is observed in the case of lodes belonging to this class. At some places, spathic carbonate of iron appears in the place of pyritic minerals.

VI. *Clinœdritic lead and zinc formation.**—The nature of the association of minerals in the lodes of this formation is remarkably definite. Of seventy-two localities, there are forty-one where quartz is the initial member of the series, six where it is blende, six where it is bitter-spar, five where it is rose-spar, five where it is spathic carbonate of iron, three where it is galena, three where it consists of galena and blende, and four where it is either brown iron ore, lamellar heavy-spar, black tellurium, or grey copper ore, and copper pyrites. As in the former classes of lodes, there is sometimes no matrix of any kind, and then the ores are situated immediately upon the adjoining rock, or upon some older deposit. Sometimes, also, the bedding has been removed, and its former presence is recognizable only by impressions or quartzose pseudomorphs, thus, for instance, carbonate of manganese is either wholly or partially removed. Where quartz, bitter-spar, and rose-spar occur in pairs, they are always in the order named here. Carbonate of iron follows quartz, but is not associated with the other spathic minerals. Sometimes calc-spar occurs, but always as a later production than the metalliferous minerals. Among these latter, galena is always the oldest. Among the pyritic minerals mispickel does not occur, nor is it found in any subsequent lode formation. Magnetic pyrites is also wanting. There are very few exceptions to the order of succession above stated. Carbonate of iron and blende appear generally in repeated alternations, in some instances, as many as five times. This is also the case with carbonate of iron and galena. At Jaroso, in Spain, the latter minerals occur in numerous alternating layers. Breithaupt has observed as many as forty such layers of carbonate of iron, and seven of galena.

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* So called because Breithaupt classes together under the general term of clinœdrites argentiferous grey copper, brittle sulphuret of silver, tennantite, sulphuret of tin, etc.

VII. *Iron-spar formation*, with other iron ores. The usual associated minerals comprise quartz and bitter-spar, which are always older, and lamellar heavy-spar, which is always more recent than the spathic carbonate of iron.

VIII. *The copper formation* comprises those lodes in which sulphuretted copper ores are associated with iron pyrites, but not with galena or blende. Of fifty-three localities where such lodes occur, there are twenty-three where quartz is the initial member of the series, three where it is carbonate of iron, two where it is bitter-spar, four where it is calc-spar, fourteen where it consists of the ores themselves, and seven where the ores are attached to the adjoining rock.

IX. *Antimony formation.*—The bedding is quartz, and it is always present.

X. *Manganese and iron formation.*—Of twenty-five localities, there are eleven where quartz is the initial member, and thirteen where it consists of iron and manganese ores.

XI. *Later cobalt and nickel formation.*—Of one hundred and twenty-eight localities, chiefly in the Saxon Erzgebirge, there are eighty-eight where quartz or hornstone is the initial member, in the remainder, it is either iron- baryta- fluor- calc- or bitter-spar, and sometimes the minerals themselves. In other countries, iron-spar is generally the initial member, or there is a great diversity of minerals.

XII. *Fluor-spar, baryta-spar, lead and zinc formation.*—Of sixty localities, there are twenty-one where the initial member is fluor-spar, four where it is baryta-spar, five where it is barytocalcite, nineteen where it is quartz, and eight where it consists of the ores themselves. In five instances, quartz occurs as a more recent member. Fluor-spar and baryta-spar have sometimes been partially removed. Among the ores, galena occurs, although in limited extent, as the most characteristic member, and, sometimes, it is unaccompanied by blende and pyrites. There is not any other formation in which so many products of the alteration of galena are met with as in this. Sometimes slabs of galena occur with hexahedral impressions of fluorite and fragments of this mineral. But, as galena also occurs between brown spar and calc-spar, these minerals may be removed while the fluorite is preserved. The galena, also, presents rhombohedric impressions of calc-spar. Breithaupt describes a specimen in which there is a frequently-repeated alternation of the lode matrix and galena, there being, at least, five layers of galena, four of baryto-calcite, three of calc-spar, three of fluor-spar, and one of blende.

XIII. In the *baryta-spar, copper formation,* lamellar heavy spar is the lode matrix; then follow copper pyrites, variegated pyrites, etc.

XIV. *Silver formation.*—Of sixty-six localities there are twenty-two where quartz is the initial member, eight where it is calc-spar, seven where it is baryta-spar, three where it is carbonate of iron, two where it is bitter-spar, two where it is rose-spar or baryto-calcite, and twenty-two where the ores themselves commence the series. The succession of silver ores is everywhere the same, and they follow galena. Native silver is the most recent member of the series, except where, as is rarely the case, it has been again converted into sulphide of silver. The richest silver ores are found upon baryta-spar lodes.

Cinnabar is, also, associated with baryta-spar; even the mercurial grey copper occurs at Saalfeld under similar circumstances, and is older than the baryta-spar.

Phosphates are among the most recent of lode minerals, and they are never met with at any depth. Breithaupt mentions several instances of the occurrence of zeolitic minerals upon lodes.

The conclusions that may be drawn from the association of minerals constituting lodes will be pointed out on treating of the production of metalliferous minerals.

A.—SILICATES OF METALLIC OXIDES.

All basic metallic oxides may be combined with silica, and these compounds have mostly been prepared artificially. But in chemical works little more is generally stated than that they are insoluble in water. Silicates of all electro-positive metals do not, however, occur native; among those which do occur native, the silicates of iron, manganese, cerium, lanthanium, didymium, and perhaps, also, of chromium, are the most abundant, exceeding in this respect all other compounds of these metals. Next to iron, zinc is most frequently met with as silicate, but its sulphide is, also, very generally distributed. The silicates of other metals—

copper, nickel, bismuth—are unimportant compared with the other native compounds of these metals.

In compound silicates consisting of basic oxides, and no other acid than silica, the metallic oxides may be certainly regarded as in combination with silica, if their simple silicates also occur native; but it is questionable whether this is the case with regard to those metallic oxides that occur in small amount, and which may not occur native in the state of simple silicates. In the chemical formulæ by which the composition of minerals are expressed, these small amounts of metals are not included, but this is only because they cannot be brought into conformity with the law of definite atomic proportions.

Silicates of iron.—These minerals have already* been referred to. Their occurrence with other silicates in minerals and rocks, their alteration, etc., have been fully treated of already, and it is unnecessary to enumerate the minerals in which they occur, since there is scarcely any compound silicate that is entirely free from silicate of iron.

Silicates of Manganese have also been treated of.† They are as frequent as the silicates of iron, being almost always associated with them, though in very much smaller amount.

Cerite from a deposit of copper pyrites in the gneiss near Riddarhytta (Sweden), consists of 1 eqt. silica and 3 eqts. protoxide of cerium, with oxides of lanthanium and didynium. These oxides also occur in the following compound silicates. The orthite imbedded in the granite and gneiss of Sweden and Norway contains oxides of cerium, lanthanium, and probably also oxide of didynium; that in the limestone of the metalliferous deposits at Tunaberg contains from 4·56 to 21·43 per cent.; that in the syenite of the Plauen'schen Grund, near Dresden, contains 20·73.‡ The allanite in the granite, porphyry, gneiss, serpentine, magnetic oxide of iron, granular limestone, and upon lodes in gneiss contains both lanthanium and cerium, from 2·24 to 26·25 per cent. The oxides of these metals also exist in the bodenite from oligoclase. Oxide of cerium exists in pyro-orthite, in the tritomite from syenite, with water and carbon. Hyposklerite also contains both oxides. Berzelius discovered cerium in gadolinite. The amount varies from 3·4 to 16·69 per cent. After the discovery of lanthanium it saw found in the gadolinite from Hittertoë and Ytterby. Oxide of cerium also exists in yttro-titanite, in erdmanite, and mosandite.

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* English edition, ii, 129.

† Ibid. ii, 133.

‡ Zschau.—N. Jahrb. für Mineral, etc., 1852. p. 652.

Silicate of uranium occurs only in thorite from the syenite in Lövön, on the coast of Norway. A few other compound silicates contain only traces of oxides of uranium.

Silicate of chromium occurs only in compound silicates. A mineral from Volterra (Tuscany) is pure hydrated silicate of chromium and alumina; an earth from the same place is a mixture of some silica and 5·77 per cent. oxide of chromium, with alumina These minerals, as well as the chrome iron ore associated with them, are described by Bechi as products of the diallage in the euphotide, originating from the action of former exhalations of sulphuretted hydrogen, traces of which are recognizable in this locality. Oxide of chromium occurs also to the extent of 21·84 to 22·54 in the chrome-garnet of the Ural, associated with chrome-iron ore; in the red garnet of Bohemia to the amount of 2 to 4·18 per cent. The presence of chromium here is of interest in connection with the occurrence of chrome iron ore, in serpentine. Pyrope contains the principal constituents of chrome iron ore, and as it may be converted into talc, it is possible that chrome iron ore might be produced at the same time. The wolchonskoite of Perm contains from 17·93 to 34 per cent. of oxide of chromium, possibly as hydrated silicate; rhodochrome of Ilkul contains 5·5 per cent.; and the chrome-mica of Schwarzenstein in the Tyrol, contains 3·95 per cent.; small quantities of chromium exist in Miloschin, the schillerspar of the Baste, in a mineral resembling diallage, in the euphotide of Fiumalto, in emerald, some kinds of olivine, in some rocks, as, for instance, a serpentine.

Silicate of zinc occurs in sedimentary strata, in transition limestone, as bunches, beds, and irregular layers, and shows its sedimentary origin. Its occurrence in metalliferous veins, in transition limestone, grauwacke, lias, variegated sandstone, granite and gneiss shows that these rocks contain silicate of zinc, which is transferred to the fissures by the action of water. This mineral is hydrated, and contains 2 eqts. silica, 6 eqts. oxide of zinc, and 3 eqts. of water. Some varieties seem to contain 4 eqts. of water, and probably are also mixed with carbonate of zinc. The silicate of zinc at Limburg contains 0·276 per cent. of oxides of lead and tin; and that at Neotschinsk 2·7 per cent. oxide of lead. It seldom contains oxide of iron, and in some varieties there is but a mere trace.

Silicate of zinc occurs with the form of calc spar and bitter spar, as well as of quartz,* and is found enveloping altered crystals of galena. It also displaces pyromorphite and is displaced by malachite. These pseudomosphs show that silicate of zinc is dissolved by water. According to my experiments the artificial silicate is so sparingly soluble that its presence is not recognizable by sulphide of ammonium. It requires for solution 185,440 parts of water. The native silicate dissolves in 3,692 parts of water, saturated with carbonic acid.* Monheim states it dissolves without decomposition in carbonated water, and it has probably been deposited from such solutions.

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* English edition, ii, 60. No. 35.

C. Riegel† found the zinc ores at Wiesloch to contain:—

	I.	II.	III.	IV.	V.
Silica	24·80	20-66	8,34	7·65	2·60
Carbonic acid	4·37	13·06	6·50	7·00	12·10
Oxide of zinc	63·33	52·04	79·64	80·25	72·30
Peroxide of iron	0·80	2·35	1·20	1·04	1·05
Alumina	0·55	0·40	0·36	..	0·48
Lime	0·19	0·21	1·85	·10	0·30
Water and loss	5·96	11·28	2·11	1·96	11·17
	100·00	100·00	100·00	100·00	100·00

I. Stalactitic, corroded zinc ore, of a pale yellow colour.
II. The same ore of a dark yellow colour.
III. The same ore, pulverulent and greyish white.
IV. The same ore, whitish yellow, scaly and laminar.
V. The same ore, greyish white, and rather laminar.

Riegel† considers that No. V is hydrocarbonate of zinc, and that the other minerals are mixtures of this substance and silicate of zinc. However, I am disposed to regard Nos. I, III, and IV as mixtures of silicate of zinc and carbonate of zinc; but No. IV contains so much water that it must be a mixture of silicate and hydrocarbonate of zinc. All these substances are evidently products of the decomposition of silicate of zinc and carbonic acid.

Williamite, or anhydrous silicate of zinc, sometimes contains small quantities of peroxide of iron, lime, and magnesia. The pseudomorphs of this mineral, after silicate of zinc, show that the latter may lose its water.‡

Troostite is a variety of the same mineral, in which oxide of manganese is substituted for oxide of zinc.

Oxide of zinc also occurs, though very rarely, in compound silicates. The most remarkable instance is its occurrence in augite at the iron ore mines near Sparta, New Jersey. The weissiet from the chlorite slate of Fahlun contains 10·3 and kakoxen contains 1·23 per cent., but it is uncertain whether it exists as silicate.

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* English edition, ii, 481.
† Archiv der Pharm, 2, lviii, 29.
‡ Blum.—Nachtrag, ii, p. 13.

Silicate of Copper.—Chrysocolla occurs together with malachite, blue carbonate of copper, copper pyrites, etc., and is very abundant in some copper lodes at lake Superior.* The amount of silica varies between 26 and 40 per cent., the oxide of copper between 28 and 42·6 per cent., and the water between 12 and 28·5 per cent., with more or less protoxide of iron, lime, and magnesia. The presence of carbonic acid admits of the conclusion that there is an admixture of malachite. This mineral occurs pseudomorphous after carbonate of lead † and libethenite.‡

The blue carbonate of copper occurring with malachite, tile ore and oxide of copper, in the Schappach valley in Baden, is hydrated silicate of copper, containing 45·5 per cent. oxide of copper.

The dioptase occurring in small veins in the limestone at Karkalinsk consists of two equivalents silica, three oxide of copper. and three water.

Artificially prepared silicate of copper, digested with water, was found to dissolve in 98021 parts of water, the composition of the digested silicate being:—

Silica	0·11
Oxide of copper	0·89

This solubility of silicate of copper in pure water shows that carbonate of lead may be displaced by silicate of copper; but the large preponderance in the amount of oxide of copper in proportion to silica admits of the conclusion that the solution of the silicate was attended with some degree of decomposition by the carbonic acid always present even in distilled water.

Oxide of copper is present in many hydrated compound silicates, and to the extent of from 0·25 to 19·2 per cent., in most specimens of allophane occurring in irregular cavities in beds of iron or copper ores. Glocker § describes a very recent deposit of allophane in an old mine, when copper pyrites and felspar occur, disseminated through galena. In this instance the sulphate of copper produced by the oxidation of the pyrites reacted with the alkaline silicate resulting from the decomposition of felspar and mica in the adjoining mica slate, and the silicate of copper so produced, combined with the silicate of alumina, also furnished by the decomposition of these minerals, and with water, to form allophane. This is a striking illustration of the fact that considerable quantities of the very sparingly soluble silicate of alumina may be removed by water, even in a comparatively short period, and it is interesting in connection with the numerous cases of alteration that can only be referred to a removal of silicate of alumina.

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* Foster and Whitney.—Report on the Geology of the Lake Superior district, ii, 101.

† Blum.—Op. cit., p. 311.

‡ Sillem and Blum.—Nachtrag, ii. 122.

§ Der blaue Stollen, bei Zuckmantel.—Pogg. Ann., lxxxviii, 597.

Oxide of copper is present also in the esmarkite from the granite at Bräkke, to the amount of 10·45 per cent., with lead, cobalt, and titanium; the praseolite of Brevig contains 0·5 per cent. with lead, cobalt, and lime; tritonite, 4·62 per cent. with manganese, zinc, and tungsten; orthite and cerite contain a trace; an asbestiform mineral at Reichenstein passing into diopside contains 0·4; the analcime at Lake Superior is coloured green by silicate or carbonate of copper that at Eagle harbour containing metallic copper; the datolite at Lake Superior is also coloured red by suboxide of copper, near the copper lode, and the prehnite at this place contains 1·04 per cent. suboxide of copper.* The nontronite at Montmart, near Autun, contains 0·9 per cent. oxide of copper.

A few anhydrous compound silicates also contain oxide of copper; thus the green felspar, called amazon-stone, in Siberia, contains 0·3 per cent.; the isophyr from granite, and from a peculiar breccia near Edinburgh, contains 1·94; fayalite from a volcanic rock, 0·3 to 2·3; the epidote at St. Marcel, in Piedmont, 0·4; and the eudialite of the gneiss at Kangerdluarsuk in Greenland, 0·95 per cent.

Silicate of Nickel does not occur uncombined with other silicates. The pimelite of Silesia consists of hydrated silicate of nickel and silicate of magnesia; true pimelite, however, contains only 15·63 per cent. oxide of nickel and 38·12 water, while the above mineral contains only 5·23 per cent. water. Another specimen of pimelite analysed by Bäer contained 2·78 per cent. of nickel, with 21·03 water and bitumen. Olivine also contains from 0·32 to 0·37 per cent. oxide of nickel; serpentine, from 0·22 to 0·9; talc, from 0·24 to 0·39; and the ash from the eruption of Hecla, in 1845, contained traces of nickel and cobalt.

Artificially prepared silicate of nickel dissolves in 59821 parts of water, the dissolved substance consisting of equal parts of silica and oxide of nickel.

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* Foster and Whitney.—Loc cit., pp. 95, 101, and 107.

Silicate of Bismuth occurs together with quartz, bismuth ochre, and metallic bismuth, at Schneeberg, and at Braunsdorf near Freiberg. It appears to consist essentially of silicate of bismuth containing 22·23 per cent. silia and 69·38 oxide of bismuth, but whether the phosphoric acid and fluorine it contains are combined with bismuth or oxide of iron, is uncertain. Hypochlorite occurs on lodes in the clay-slate at Schneeberg, and in the mica-slate at Johanngeorgenstadt together with metallic bismuth, and contains 50·24 per cent. silica, with 13·03 oxide of bismuth. Although these proportions differ essentially from those of silicate of bismuth, it is worth mentioning that this mineral contains phosphoric acid, together with protoxide of iron and alumina.

Silicate of Cobalt does not occur as a mineral, and it is uncertain whether it exists even in compound silicates. The black earthy cobalt at Rengersdorff, in Upper Lusitania, contains 19·4 per cent. of the oxides of cobalt and manganese, together with alumina and silica; that at Saalfield contains oxides of cobalt and manganese. If the former metal is in the state of peroxide, the amount would be 35·47 per cent. This mineral also contains peroxide of iron, arsenous acid, alumina and magnesia. Rammelsberg describes the black earthy cobalt at Camsdorf, near Saalfield, as a compound of two equivalents of peroxide of manganese with one equivalent of the oxides of cobalt and copper. Gottlieb found that the brown iron ore from the river Santée, in North Carolina, contained 0·261 per cent. oxide of cobalt with much silica.

Silicate of Silver has not been met with native, either alone or in compound silicates. Since silver has hitherto been found only in lodes, and not in rocks, or only in the vicinity of lodes; it becomes a question what the state of combination was, in which it was carried into its present situation. Oxide of silver being a strong base, it would seem quite possible that there may be a native silicate.

Silicate of silver artificially prepared in the wet way, is a dirty yellow coloured curdy mass which is sensibly soluble in pure water, more so indeed than any other metallic silicate.

Silicate of Lead is unknown as a mineral, or even as a constituent of compound silicates.

The silicate of zinc at Limburg contains 0·28 per cent. oxide of lead with a trace of oxide of tin; that at Nertschink contains 2·7 per cent.; a small quantity has been found in the orthite of 0·8 per cent. in thorite 0·16—1·01 per cent. in wolchonskoite, 1·8 per cent in fayalite, and 0·45 per cent. together with lime, copper, cobalt, and titanium, in the esmarkite of the Brevig granite.

Among the useful metals there is none, besides iron and manganese, which is of such frequent occurrence as copper, though always so scanty in rocks. Frick* first detected oxide of copper in three specimens of clay slate; it was not separable by acids, but remained in the portion decomposed by fusion with carbonate of bayrta. List† also found 0·05 and 0·06 per cent. in green Taunus slate, and I have found about the same quantity in the slate adjoining an iron ore vein at the Pferd mine; in another, at the Fredrich Wilhelm mine, 0·3 per cent., which was in a state of combination not acted upon by acids. The clay-slate of the Appolinarisberg, near Remagen, was also found to contain traces of copper. A specimen of clay-slate from Lobenstein was observed by Breithaupt to have a cupreous incrustation upon the surfaces of the laminæ, and I detected in it both copper and lead.

The ashes of coal also contain metallic oxides; arsenic was detected by Daubree,‡ and Richardson§ found in the ashes of a coal

Titanic acid	7·01
Silica	1·84
Sulphuric acid	21·20
Chlorine	9·57
Magnesia	1·01
Potash	18·34
Soda	6·87
Peroxide of iron	26·99
Oxide of zinc	2·03
„ cadmium	1·42
„ nickel	1·38

Supposing the other acids to be combined with the bases, the titanic acid, silica and peroxide of iron would be in the same proportion as in the titaniferous iron ore of Arendal, according to Mosander's analysis.

Some varieties of melaphyr contain a sensible amount of zinc,‖ and according to Daubree‖ the basalt of the Kaiserstuhl contains both antimony and arsenic. Redtenbacher also found 0·012 per cent. oxide of copper in the phonolite of Teplitz.

Brown iron ore sometimes contains small quantities of copper;

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* Poggend. Annal., xxxv, 193.

† Annal der Chemie. and Pharmacie, lxxxi, 181.

‡ Op. cit.

§ Liebig and Kopp's Jahresbericht für, 1847—48, p. 1120.

‖ Annal. des mines (4) xix, 669, 257.

the psilomelan of Ilmenau also contains about 0·04 per cent. oxide of copper, and that of the Skidberg, in Sweden, contains 0·03 per cent. oxide of cobalt. Iron ochre frequently contains traces of arsenic. Rammelsberg found in the iron ochre deposited round the Alexisbad springs, from 0·025 to 0·958 per cent. arsenic, 0·017 copper, and 0·003 tin. Hence it would appear that the rocks from which iron and manganese ores have originated by the decomposition of silicates of those metals, also contained traces of other metallic oxides, probably in the state of silicates, which were decomposed and removed by water, together with the carbonate of iron.

B.—ALUMINATES.

The few aluminates that are known may be treated of together with silicates, though they are relatively of the most recent origin.

Gahnite, which occurs in the talc-slate, granite, and mica-slate near Kupferberg, is an aluminate of zinc, iron, and magnesia, in which the oxide of zinc amounts to between 24·25 and 34·8 per cent.[*]

The black spinelle—kreittorite—occurring in mineral deposits in the granite at Bodenmais, Bavaria, is an aluminate of zinc, iron, magnesia, and manganese, in which the oxide of zinc amounts to 26·67 per cent.

The halloysite of Altenberg near Aix-la-Chapelle, contains 1·23 per cent. oxide of zinc, but it is uncertain whether it exists as aluminate or silicate.

The dysluite of Sterling, New Jersey, contains 16·8 per cent. oxide of zinc, probably combined with alumina. There is a connection between this mineral and crystalline franklinite, which occurs at the same place, together with the red oxide of zinc, and contains from 9·3 to 10·34 per cent. oxide of zinc, with some protoxide of manganese and magnetic oxide of iron, but no alumina. C. Bechi[*] found a mineral associated with franklinite and zinc blende at Bottino and Toscana, consisting of 31·72 oxide of zinc, 47·45 peroxide of iron, and 20·82 water.

The mineral occurring together with galena and carbonate of lead, in the lead mines of Huelgoët, in Brittany, appeared to be hydrated aluminate[†] of lead, but Damour found that it contained phosphoric acid, and regarded it as a mixture of phosphate of lead, chloride of lead, and hydrate of alumina. The crystallized phosphate of lead occurring at the same place, contains the same constituents in different proportions. That of la Nussiere, near Beaujeu, appears to be a mixture of aluminate of lead, with phosphate of lead. A sinter-like deposit from the mine Rosieres, near Carmeaux, coated with basic arsenate of copper, appears to be a hydrated mixture of phosphates of alumina and lead, probably with arsenate of copper. The green chrysoberyll of the mica-slate at Ura contains 0·29 per cent. of the oxides of copper and lead, but it is uncertain whether these oxides exist as aluminates, and whether aluminate of lead occurs at all. The chorospinelle of the talc-slate at Slatoust, contains from 0·27 to 0·62 per cent. oxide of copper, and the green chrysoberyll of the mica-slate in the Ural, contains 0·29 per cent. of the oxides of copper and lead.

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[*] Zeitschrift d. deutsch. geol. Ges. III., 12.

[†] Sillim. Americ. Journ. 2, xiv, 62.

C.—SULPHIDES.

There cannot be any doubt that among the metallic sulphides occurring in lodes, those of which the metals occur as silicates in the adjoining rock are of later date than these silicates. It is only the silicates of iron, manganese, cerium, lanthanium, didymium and chromium, whose existence in rocks has been positively ascertained. But among these metals only iron and manganese seem combined with sulphur, so that the above relation can obtain only in the case of the sulphides of iron and manganese, and the corresponding silicates. All other sulphides must be regarded as the oldest compounds of the metals they contain, for though there is much to favour the opinion that these sulphides, like those of iron and manganese, originate from the adjoining rock of lodes; and though it is very probable that the metals formerly existed as silicates in the rock, there is no positive evidence to this effect.

Since there is only a single instance known of a sulphide being pseudomorphous after an oxidized compound of the metal it contains, viz. galena with the form of pyromorphite; this circumstance also leads to the conclusion that the sulphides are the oldest compounds of metals. However too much importance must not be attached to these facts, for neither sulphides of manganese, iron pyrites nor magnetic pyrites, occur with the form of the oxidized compounds of manganese or iron.

It would appear therefore that the metamorphic processes going on in rocks, are not of such a nature as to effect the conversion of iron-spar, or hematite, into iron pyrites, with retention of the original form, although this alteration may be easily effected artificially.*

This fact is a striking proof of the wholly untenable character of the hypothesis that pseudomorphs can have been produced by igneous action.

It is a very important fact that though pseudomorphous sulphides do occur it is only after other sulphides. If therefore lodes which now contain sulphides formerly contained oxidized ores which were converted into sulphides, the form of those minerals must have been destroyed during the alteration. If the oxidized compounds had been introduced into the lodes by the action of heat, and had been subjected while still hot to the action of sulphuretted hydrogen, they would have been converted into sulphides with retention of their form. It is therefore most probable that sulphides were either deposited directly in fissures in the wet way, or else that they were produced by the alteration of oxidized compounds, which had previously been deposited from solution.

Iron pyrites, copper pyrites, galena, and most native sulphides decrepitate when heated. Artificially prepared sulphides, such as those produced in some metallurgical operations, do not decrepitate. Cotta † describes a substance filling a fissure in the bed of a reverberatory furnace, which had the appearance of a mixture of galena, blende, copper pyrites, variegated pyrites, and sulphide of copper. Chemical analysis, however, showed that besides galena there was only a substance resembling copper pyrites, and another was sulphide of copper and lead. The inference sought to be drawn from this fact, that metalliferous lodes have been filled with sulphides by sublimation in a similar manner, involves the assumption that sulphides so produced by heat would acquire the character of decrepitating when immersed in watery liquids. Cotta ‡ admitted, however, that gangue substances—quartz, calc-spar, heavy spar, etc.—cannot be regarded as the products of igneous infiltration or sublimation.

Although the sulphides prepared by precipitation from solutions of metallic salts are mostly amorphous masses without lustre, they may be obtained artificially with metallic lustre by the slow action of sulphuretted hydrogen upon very weak solutions, and these are precisely the conditions under which the production and alteration of minerals take place in rocks and lodes. The slow infiltration of water containing a trace of lead, into a fissure where the air is slightly charged with sulphuretted hydrogen, might therefore give rise to the production of galena in a perfectly crystalline state. And in the same manner that sulphide of zinc, produced from silicate of zinc by the action of sulphuretted hydrogen, separates completely from the silica,* that substance may also be separated under the above conditions from the sulphide of lead produced, in such a manner as to give rise to the frequent association of galena with quartz.

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* English edition, i. 25.

† Gangstudien, ii. 1 et seq.

‡ n. Jahrb. für Mineral., etc., 1844. p. 25.

SIMPLE SULPHIDES.

The distinction between simple and compound sulphides cannot be very strictly carried out,† not only because native sulphides frequently contain small quantities of foreign metals, but also because some double sulphides are not to be separated from simple sulphides, as, for instance, sulphide of copper from copper pyrites.

Sulphide of iron.—Bisulphide of iron occurs very generally as iron pyrites, both as layers and imbedded in crystalline and sedimentary rocks.

Hydrated peroxide of iron occurs pseudomorphous after iron pyrites very frequently, and in the rocks belonging to various geological series. The alteration of the pyrites extends from the surface inwards. The edges of the crystals are generally sharp, the faces smooth and even. Sometimes there is a nucleus of iron pyrites. Generally the alteration of iron pyrites takes place when the rock in which it occurs is undergoing alteration. This is very evident in the anhydrite of the Canaria valley in Switzerland, where the small crystals of iron pyrites do not present any sign of alteration, while in the gypsum, resulting from the alteration of anhydrite, it has been entirely converted into hydrated peroxide of iron. Zippe found this to be the case also in the slate at Eula, in Bohemia. It might, indeed, be expected that the water which effects the decomposition of the rock would also determine the oxidation of the iron pyrites, and the sulphuric acid thus produced would have a still further influence in decomposing the rock.

Scheerer ‡ examined several products of the decomposition of iron pyrites occurring on the sides and roof of a cave in the alum slate at Modum, in Norway, with the following results—

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* English edition, ii, 62.

† Gangstudien, ii, 1, et seq.

‡ Poggend. Annal. xlv., 188.

	I.	II.	III.
Peroxide of iron	80·73	49·63	46·74
Sulphuric acid	6·00	32·44	32·11
Soda	..	5·20	..
Potash	..	..	7·88
Lime	..	..	0·64
Water	13·57	13·11	13·56
	100·30	100·38	100·93

I. Dark brown substance, insoluble in water, disseminated through the rock.

II. Pale yellow-coloured layer in stalactitic masses, containing a trace of gypsum, and situated under No. I, but quite distinct from it. This bed is covered with a whitish crystalline coating of pure gypsum.

III. A mineral from the brown coal at Bilin.*

Blum† describes a specimen, from the mercury mines of the Stahlberg in Rhenish Bavaria, with sulphate of iron, presenting the form of iron pyrites.

If the conversion of iron pyrites into brown hematite is determined by its previous oxidation, it becomes a question what became of the sulphuric acid produced in the alteration. The occurrence of these pseudomorphs in beds of limestone, leads to the conjecture that the acid was taken up by limestone. This is very evident in the case of the brown iron ore in the grauwacke limestone at Campo, in Brazil, where the limestone all round has been converted into gypsum. In the granular limestone of Ells,‡ in Moravia also, the limestone surrounding a bed of decomposed iron pyrites has been converted into gypsum.

In the reaction of sulphate of iron with the carbonate of lime dissolved in carbonated water, the sulphate of lime would be removed in solution, and the gypsum coating the above-mentioned bed No. II, indicates that bicarbonate of lime was really the agent of decomposition in that instance. If the 6 per cent. sulphuric acid in No. I were removed, there would be hydrated peroxide of iron left. The bicarbonates of magnesia and alkalies would also effect the decomposition of the sulphate of iron, and, in this respect, the presence of alkalies in Nos. II and III, is worthy of notice.

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* Rammelsberg.=Ibid, xliii, 132.

† Op, cit., p. 206.

‡ Bone.—Geognost. Gemälde von Deutschland, p. 46.

Taking the mean density of iron pyrites as 5·04, that of brown hematite as 3·655, and the amount of water it contains as 14·71 per cent., it would seem that there would be an increase of volume to the extent of 7 per cent.; but if the brown hematite produced was of the maximum density, 3·91, there would not be any alteration of volume in the conversion of iron pyrites into brown hematite.

Ullmann[*] describes cubical pseudomorphs of compact red hematite, together with others of compact brown hematite, as occurring at the mines near Beresowsk, in Siberia. Sillem[†] also found at Schmalkalden, octahedrons, consisting of hydrated peroxide of iron, resulting from the alteration of iron pyrites; while others of them consisted of peroxide of iron with only a thin crust of hydrated peroxide.

Most likely the production of red hematite takes place subsequently to that of hydrated peroxide, and not directly from the iron pyrites.

It must also be regarded as possible, that iron pyrites may undergo conversion even into iron-spar. Stenhouse[‡] found that the roots, etc., of plants, as well as peat and coal, reduce persulphate of iron to protosulphate; so that if some persulphate of iron were produced by the oxidation of iron pyrites, and then reduced to protosulphate, this might be again converted into carbonate of iron by reaction with water containing bicarbonate of lime in solution.

The pseudomorphous white iron pyrites after iron pyrites[§] is remarkable as an instance of the conversion of a substance into its dimorphous condition. Sillem[‖] describes pseudomorphs indicating the contrary alteration of white iron pyrites into ordinary pyrites occurring at Rodna, in Transylvania.

The displacement pseudomorphs of iron pyrites after calc-spar, heavy-spar, quartz, etc., are further evidence of the production of iron pyrites from solutions of carbonate of iron in carbonated water and sulphates, under the reducing influence of organic substance.

So far as the evidence afforded by pseudomorphs extends, it would seem that iron pyrites cannot be produced under the influence of organic substance from iron-spar, brown or red hematite, except the oxide of iron first passes into solution as carbonate.

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[*] Blum.—Op. cit., p. 187.

[†] Ibid., p. 390.

[‡] L'Institut. 1844. No. 566.

[§] Blum.—Op. cit., Nachtrag, p. 149.

[‖] Ibid., p. 399.

White iron pyrites is less frequent than iron pyrites, but has the same composition and resembles it in other particulars.

White iron pyrites undergoes conversion into brown hematite, though pseudomorphs of this kind are met with much less frequently than those after ordinary iron pyrites, except where white iron pyrites occur in clay, as in the brown coal-measures at Littmitz in Bohemia.*

Magnetic pyrites is also less frequent than iron pyrites. It is a monosulphide. That of the Gap mine, Lancaster county, Pennsylvania, contains from 2·9† to 4·55 per cent. nickel, 1·3 copper, 0·27 lead, and 1·7 arsenic.‡ The copper pyrites and iron pyrites, associated with this mineral, do not contain nickel.

The lodes near Frieberg not unfrequently contain pseudomorphs of iron pyrites after magnetic pyrites, though the latter mineral occurs but very rarely. § Wherever the two minerals are associated the iron pyrites is always the more recent of the two; and probably much of the iron pyrites in lodes was originally magnetic pyrites.

In the conversion of magnetic pyrites into iron pyrites a portion of the iron would be removed and, consistently with this, it appears that in the neighbourhood of Frieberg, where this alteration has taken place very extensively, the magnetic pyrites has furnished material for the production of iron-spar, and other minerals containing protoxide of iron. Therefore the iron has been extracted from magnetic pyrites by the action of carbonated water. In this alteration the magnetic pyrites must lose 25·54 per cent. of iron; and, since the density of iron pyrites is greater than that of magnetic pyrites, the volume of the former would amount to only 68 per cent. of the latter. The pseudomorphs do almost always indicate a reduction of volume.

Magnetic pyrites often occurs mixed more or less intimately with iron pyrites. G. Rose || mentions the occurrence of a small crystal of iron pyrites imbedded in another of magnetic pyrites, and a mixture of iron pyrites with magnetic pyrites occurring at Barèges is mentioned by Stromeyer. G. Rose ¶ also observed

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* Blum.—Op. cit., p. 197, Nachtrag, p. 111.

† A. Genth.—Chem. Pharm. Centralblatt, 1852, p. 73.

‡ Boye.—Sillim, Journ. (2) xiii, 219.

§ Breithaupt.—Paragenesis, etc., pp. 130, 157, 161, and 163.

|| Reise nach dem Ural. ii, 117. Poggend. Annal. lxxiv, 293.

¶ Gilbert's Annalen, xlviii, 186.

small quantities of peroxide of iron on the faces of the magnetic pyrites of Bodenmais and Trumbull, in Connecticut, probably resulting from oxidation of the pyrites. If at the same time the sulphur remained unacted upon, iron pyrites might have been produced. Since magnetic pyrites is most frequently amorphous, the iron pyrites resulting from it would present its own crystalline form, so that there would not be any indication of the change that might have taken place.

Sulphide of Manganese is a monosulphide. It occurs rarely in lodes, together with tellurium ores, iron pyrites, grey copper, and also in quartz veins.

Sulphide of Zinc occurs very frequently as zinc-blende, in lodes and metalliferous deposits, associated with most ores, and sometimes constituting the matrix of the lode. It occurs more rarely disseminated through rocks—granite, mica-slate, basalt, etc., in drusy cavities of dolomite, cupreous-slate, limestone, lias, and basalt, as thin veins in coal and sphærosiderite, and as a very recent deposit.* Zinc-blende is rarely pure, generally containing iron, and sometimes manganese also. That of Marmato near Popayan—marmatite—consists of three equivalents, sulphide of zinc, with one equivalent, sulphide of iron, and often contains a small amount of cadmium. That of Raibl in Carinthia contains traces of antimony and lead.

Zinc-blende undergoes conversion into calamine, as at the outcrop of a thick lode, near Altenbrück. Near Bergish-Gladbach, where the calamine occurs between dolomitic limestone of the transition series, and brown-coal clay, there are a great number of detached fragments of blende imbedded in this clay. The larger masses are nodular and are converted into calamine at the surface, and in the drusy cavities. Both zinc ores also occur between the limestone and the strata of the brown-coal series. All the circumstances here show that these ores are no longer in their original situation; but that they have been washed down during the deposition of the brown-coal series. It is remarkable that at the southern portion of the limestone ridge, where the zinc ores do not occur, there is a bed of gypsum, two inches thick, between the limestone and clay. It may be that the sulphuric acid produced during the conversion of the zinc-blende into calamine was carried to this spot by water, and converted a portion of the limestone into gypsum.

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* English edition, i, 164.

Blende occurs as a displacement pseudomorph after calc-spar.* Most likely the displacement was not effected directly but by the reaction of organic substance with sulphate of zinc dissolved in water while the carbonic acid thus produced facilitated the removal of the carbonate of lime by the water. It may be also that the sulphate of zinc and carbonate of lime were mutually decomposed; in which case the sulphate of lime would be reduced by organic substance to sulphide of calcium, which converted the oxide of zinc into sulphide.

The oxide of zinc in gahnite† appears also to be susceptible of conversion into zinc-blende. Websky‡ discribes a gahnite-crystal converted into compact zinc-blende at the surface, but unaltered at the interior.

Brown iron ore also occurs as a displacement pseudomorph after zinc-blende at Geyer.§ The removal of the metallic sulphides by oxidation, and solution of the products of this alteration is easily understood; for there is no sulphide that is not liable to oxidation, and all surface-water contains oxygen. The ferruginous mineral water, and almost every spring water show that carbonate of iron can exist in solution together with the oxygen in water, without undergoing oxidation till exposed to the influence of the atmosphere. Hence it may be understood that such water exercises an oxydizing influence upon sulphides, and removes the sulphates thus produced, while carbonate of iron is deposited in their place, and gradually undergoes conversion into brown hematite.

The volzite occurring together with zinc-blende, and several other sulphides in quartz at Pont-Gibaut, Puy de Dome, consists of 82·82 per cent. sulphide of zinc, 15·34 oxide of zinc, and 1·4 peroxide of iron. This mineral has, probably, been produced by ozidation of sulphide of zinc; the sulphate of zinc might have been decomposed by calcareous water, and the resulting sulphate of lime washed away; but in this case it does not appear why the carbonate of zinc has not remained.

Sulphide of Copper occurs in lodes and beds, together with copper pyrites, variegated pyrites, malachite, azurite, green copper, red oxide of copper, tile ore, and metallic copper; in cupreous slate, and as a petrifying material of plant remains; it occurs more rarely in rocks and in clay. At Lake Superior, baryta-spar occurs covered with sulphide of copper.* It is a disulphide, containing,

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* Silem.—n. Jahrb. für Mineral., etc., 1851. p. 578.

† See ante, p. 449.

‡ Zeitschrift d. deutsch. geol. Ges. v, 435.

§ Nöggerath.—N. Jahrb. für Mineral, etc., 1838, p. 307.

Sulphur	....	....	20·27	100·00
Copper	....	....	79·73	

but it always contains some iron, from 0·28 to 3·33 per cent., and Plattner found oxide of copper in the sulphide of copper of Bogstowck.†

Variegated copper pyrites occurs in lodes, together with sulphide of copper, copper pyrites, malachite, azurite, green copper, red copper, tile ore, metallic copper, etc.; also in cupreous slate and, but rarely, in rocks. Careful analyses by Plattner and others, show that the compact variegated copper pyrites rarely or ever has a definite chemical composition, but is almost always mixed with sulphide of copper, copper pyrites, and often, also, with small quantities of oxides of copper and iron.‡ Taking his analysis of the variegated pyrites of Cornwall, as representing the purest variety, it consists of

Sulphur	....	6	28·24		Sulphide of copper	...	69·91
Copper	....	6	56·76	or	Sulphide of iron	....	30·09
Iron	....	2	14·84				
							100·00
			99·84				

Copper pyrites occurs very frequently in lodes and beds, with other copper, iron, and lead ores, in various geological series. It occurs more rarely in rocks, such as cupreous-slate, constituting the coating of fossil fish, also in drusy cavities of cupreous slate, imbedded in shelly limestone, chlorite-slate, and in syenite, in cavities of amygdaloid rocks, and limestone, in clay, in fissures of coal, and sphœrosiderite of the coal measures. It consists of

Sulphur	....	4	35·05	Sulphide of copper	....	43·23
Copper	....	2	34·47	Sulphide of iron	....	56·77
Iron	....	2	30·48			
						100·00
			100·00			

Covellite occurs in lodes, cupreous-slate and shelly limestone, together with other copper ores, and also as an incrustation of lava and scoria. Its composition is

Sulphur	....	1	....	33·70
Copper	....	1	....	66·30
				100·00

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* Foster and Whitney, Op. cit. p. 96.

† Poggend. Annal. xlvii, 358.

‡ Ibid, p. 359, et seq.

Walchner found this mineral contained small quantities of iron and lead, and Grim found it was mixed with 3·39 per cent. iron pyrites, 10·57 peroxide of iron, and 18·63 per cent. quartz.

Sulphide of copper undergoes alteration into variegated pyrites and copper pyrites. The pseudomorphous variegated pyrites after sulphide of copper, often contains neuclei of the latter mineral. In the conversion of 69·91 parts of sulphide of copper into variegated pyrites, 30·09 parts of sesquisulphide of iron must enter into combination with it, so that the increase of volume would amount to 63·66. It is only in those pseudomorphs, however, in which the alteration commenced at the interior, that Blum has observed an exfoliation of the mass at the terminal planes, and it is not stated whether it amounts to so much as would correspond with such an increase of volume. When the alteration commenced from the exterior, its progress would have been attended with a bursting of the exterior layers in proportion as the sulphide of iron penetrated into the mass, if some of the sulphide of copper had not been removed. Consequently the alteration could only have been effected by interchange of constituents. This is the more intelligible from the fact that iron pyrites occurs pseudomorphous by displacement after other sulphides, and several other substances, and also since sulphide of copper is so readily removed in consequence of oxidation, as is shown by the occurrence of sulphate of copper, in mine-water, and in hollows and fissures in old copper-mines.

Haidinger * found the surface of a pseudomorph of variegated pyrites after sulphide of copper, coated with a layer of copper pyrites showing that the variegated pyrites had undergone a further alteration into copper pyrites. Varrentrapp † describes crystallized variegated pyrites that contained nuclei of copper pyrites. In the conversion of sulphide of copper into copper pyrites, 43·23 parts would be combined with 56·77 parts sulphide of iron, and consequently the increase of volume would be 164·9. It is impossible that so large an increase of volume should take place without entire obliteration of the original crystal form; and it is to this circumstance that Blum ascribes the fact that in the conversion of sulphide of copper into copper pyrites, the crystalline form is seldom preserved. In the above instance, however, this view is not applicable; and it must be supposed that, as is the case in the conversion of sulphide of copper into variegated pyrites, there was a partial substitution of sulphide of iron for sulphide of

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* Poggend. Annal. ix, 184. † Ibid., xlii, 372.

copper. Although possibly it cannot be denied, that when the form is obliterated as a consequence of the alteration, this may be due to the mere introduction of sulphide of iron, it is not the less admissible to adhere to the simpler view that there is always an interchange of constituents.

Copper pyrites occurs also as a product of the decomposition of grey copper. The incrustation of grey copper crystals with copper pyrites has long been observed, especially in the Harz. Volger[*] mentions that in the Rosenhöfer-Gangzug, near Clausthal, the iron-spar is covered with large patches of grey copper, as crystals, half an inch long, which are externally converted into copper pyrites. Sometimes there are several layers of copper pyrites, and then those which are nearest to the nucleus of grey copper are less completely developed than those outside it, and some of these copper pyrites pseudomorphs presenting the most complicated modifications of the grey copper tetrahedron, contain a perfectly rounded nucleus of grey copper. The iron-spar, bitter-spar, and heavy-spar, as well as the galena and zinc-blende, which are intimately associated with the grey copper ore, are not at all coated with copper pyrites. Most of the imbedded faces of the grey copper crystals have not any coating of copper pyrites, but often present specks which are also found in the interior of the crystals. Hence it appears that the copper pyrites has been produced by the alteration of the grey copper ore, a change which is further indicated by the circumstance that the outer portion of the grey copper nucleus, underneath the coating of copper pyrites, is more or less porous than the inner portion of the neuclus, or the uncoated surface of the crystals.[†]

Since the composition of grey copper ore varies very much, it is not easy to form a clear conception of the alteration. Among the numerous analyses of grey copper, those are selected which give the maximum and minimum amounts of copper and iron, and which refer to specimens occurring in localities where copper pyrites has been found pseudomorphous after grey copper ore. The figures in column A give the amounts of constituents that may take part in the conversion into copper pyrites; those in column B, the sulphur requisite for producing disulphide of copper and sesquisulphide of iron; those in C, the sulphide of iron furnished by the iron, and requisite for conversion of the copper into copper pyrites; those in D, the copper pyrites furnished by the copper and by the iron.

[*] Poggend. Annal. lxxiv, 25.

[†] Blum.—2te Nachtrag zu den Pseudomorphosen, etc., p. 86.

	A.	B. Sulphur.	C. Sulphide of iron.	D. Copper Pyrites.
I Maximum of copper	41·57	10·57	68·46	120·60
And of iron	4·66	4·02	8·68	15·29
Maximum of sulphur ..	27·25	..	..	..
	73·48	14·59	59·78	
II. Minimum of copper ..	14·81	3·76	24·39	42·96
„ iron	5·98	5·16	11·14	19·62
„ sulphur ..	21·17	..	..	..
	41·96	8·92	13·25	
III. Copper	34·23	8·70	56·37	99·30
Maximum of iron	9·46	8·16	17·62	·31·04
And minimum of sulphur ..	19·38	..	..	..
	63·07	16·86	38·75	
IV. Copper	37·98	9·66	62·55	110·19
Minimum of iron	0·86	0·74	1·60	2·82
Sulphur	25·77	..	..	..
	64·61	10·40	60·95	
V. Copper	34·48	8·76	56·78	100·02
Iron	2·27	1·96	4·23	7·45
Sulphur	24·73	..	..	..
	61·48	10·72	52·55	
VI. Copper	35·7	9·07	58·80	108·57
Iron	4·5	3·88	8·38	14·76
Sulphur	24·1	..	..	..
	64·3	12·95	50·42	
VII. Copper	38·42	9·76	63·28	111·46
Iron	1·52	1·31	2·83	4·99
Sulphur..	25·03	..	..	..
	64·97	11·07	60·45	

	Analyzed by
I. Grey copper of Mouzaïa, in Algeria	Ebelmen.
II. Grey copper of "Habacht-Fund" mine, near Freiberg	H. Rose.
III. Grey copper, containing mercury; Porat, Hungary	v. Hauer.
IV. Grey copper ore of Kaprick, Hungary V. Grey copper ore of the Zilla mine, near Clausthal	H. Rose.

	Analysed by
VI. Grey copper ore of Clausthal	Sander.
VII. Grey copper ore of the Aurora mine, near Dillenberg	H. Rose.

From these data it appears that—

1. The amount of sulphur is always greater than is requisite for the elimination of the copper as disulphide, and of the iron as sesquisulphide, in the conversion of grey copper ore into copper pyrites, during which from 2·52 to 15·37 per cent. is separated and removed.

2. The largest quantity of copper pyrites that the most ferruginous grey copper ore can yield, upon the assumption that only the sulphide of iron existing in it combined with a corresponding quantity of sulphide of copper, in producing the pseudomorphous copper pyrites, is only 31·04 per cent., but this quantity is sometimes as small as 2·82 per cent.

3. When the whole of the copper in the grey copper ore appears in the copper pyrites, and the deficiency of sulphide of iron is supplied from without, the amount of the latter constituent varies from 42·96 to 120·6.

4. The quantity of sulphide of iron introduced varies from 13·25 to 60·95.*

It is particularly interesting to know the composition of the grey copper, whose conversion into copper pyrites has been proved by Volger and Blum to take place; for the mine in which No. V occurs is one of the places where the grey copper ore crystals with incrustations of copper pyrites are particularly fine. Calculation shows that the weight of the copper pyrites corresponds with that of the grey copper ore exactly in No. V, and very closely in No. VI. But there must have been an increase of 17·8 to 22·8 in the volume if the alteration took place in the manner above assumed, and this does not agree with Volger's statement that the crusts of copper pyrites round the grey copper ore nuclei are quite loose. Hence there must have been either a disintegration of the mass, or some sulphide of copper must have been removed during the alteration. It would be difficult to determine this point, but it is quite certain that the alteration cannot be accounted for as being determined by the amount of sulphide of iron in grey copper ore, since, in that case, only from 7·45 to 14·76 parts of copper pyrites could have been produced, and this would be less than that contained in the crusts of copper pyrites.

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* All these numbers refer to 100 parts by weight of grey copper ore.

In No. VII the increase of weight amounts to 11·46, and the increase of volume to 31·10. In speaking of the pseudomorphs of the Aurora mine, Grandjean * states, that in some instances the crystals of grey copper ore are rent, and that there are a number of copper pyrites crystals crowded together in the cracks and on some of the adjoining faces which have not undergone any alteration. Other of the faces are, however, thickly incrusted with copper pyrites, and are also much corroded. It can scarcely be doubted that these cracks are a consequence of alteration of volume, and it is therefore possible that the conversion took place without elimination of sulphide of copper.

Blum remarked that the crusts of copper pyrites upon the grey copper ore from the "Dreibruderschacht," near Frieberg, were of unequal thickness, and warty at the exterior, while at the interior there were several layers of copper pyrites, the undermost of which was not sharply detached from the grey copper ore. The two substances blend together at some places, and it is evident that the grey copper ore has been altered to a greater depth at some places than at others. Other of the grey copper crystals appear to be covered with a thin crust of variegated pyrites a circumstance also mentioned by Volger, and indicative of the conversion of the grey copper into variegated pyrites in the first instance, and the subsequent production of copper pyrites.

The general characteristics of the conversion of grey copper ore into copper pyrites, may be regarded as consisting in the abstraction of antimony, arsenic, tin, and silver, together with a portion of the sulphur, and sometimes also a portion of the copper, while sulphide of iron is substituted in their place. If the copper in grey copper ore amounts to 34·47 per cent., as in copper pyrites, the weight of the copper pyrites would equal that of the grey copper ore from which it originated. If it amounted to 29·23 per cent., the volume of the copper pyrites would be equal to that of the grey copper ore from which it originated. Among the varieties of grey copper ore analysed, there are only those of Meiseberg, in the Hartz, and of Gustav Fridrici, in Hungary, in which the amount of copper, respectively 30·47 and 30·58, approaches the above maximum. In those varieties of grey copper ore which contain less than 29·23, the conversion into copper pyrites would be attended with a diminution of volume, and in those containing more copper there would be an augmentation of volume provided none of the sulphide of copper were removed.

Copper pyrites occurs also as a pseudomorph after needle ore at

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* Jahrb. der Vereins für Naturk. im Herz. Nassau, 1851, p. 226.

Löhma, near Schleitz. In most instances there has been a c derable reduction of volume.[*] The needle ore contains, be lead, bismuth, and sulphur, from 10·59 to 12·62 per cent. of co the average amount corresponding to 33·68 parts copper pyrite a reduction of volume to the amount of 45 per cent. Since n ore does not contain any sulphide of iron, this substance must been supplied by water during the conversion into copper py

The frequent conversion of copper ores into copper pyri indicative of a great tendency to the production of a double sul On the other hand, it appears from the frequent occurren pseudomorphous iron pyrites, that it is always the bisulphi iron that is substituted for other minerals. It has already shown that the conversion of sulphide of copper into copper p may be regarded as consisting in the introduction of iron py So, likewise, the conversion of grey copper ore into copper p may be regarded as consisting in the introduction of bisulphi iron, one equivalent of the sulphur in which enters into com tion with bisulphide of copper, converting it into protosul while it is also converted into protosulphide of iron. The co sion of needle ore into copper pyrites may also be regard consisting in the introduction of bisulphide of iron.

The occurrence of pseudomorphous tile ore, malachite, covellite, after copper pyrites, shows that the latter is susceptil alteration in various ways. Instances of the conversion of c pyrites into iron pyrites and black oxide of copper are also kn At the Himmelfahrt mine, iron pyrites has been found ps morphous after copper pyrites, and slate coated with a thin of copper pyrites. One large crystal contained several cavities, lined with iron pyrites, showing that a considerable nution of volume had taken place.[†] Another specimen, Müsen, presented pyramidal crystals, corresponding to tho copper pyrites, coated with black oxide of copper, while interior consisted of a porous mixture of copper pyrites and pyrites. Those portions in which the copper pyrites form been obliterated consist only of iron pyrites. Crystals of pyrites often occur in the midst of altered copper pyrites cryst In this alteration, copper pyrites would yield 65·53 parts pyrites, and 34·47 parts copper, by the oxidation of which 4 parts oxide of copper would be produced. If no portion of mineral were removed, there would be an augmentation of wei which does not agree with the reduction of volume. Most likely, however, copper was removed in the alteration.

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[*] Breithaupt.—Berg und Hüttenmannische Zeitung, 1853. No. 24.

[†] Breithaupt.—Paragenesis, p. 29.

[‡] Bulm.—2 ter, Nachtrag, p. 75.

Copper pyrites undergoes conversion into covellite. The change commences at the surface, and progresses until the whole is converted into a porous blue mass.* In this alteration 52 parts protosulphide of copper remains, while 48 parts protosulphide of iron is removed. The diminution of volume amounts to 42·44, corresponding to the porous condition of the pseudomorphs, and is probably the reason that the crystalline form of the copper pyrites has not been retained distinctly.

The association of covellite with copper pyrites, and the occurrence of incrustations of the former mineral on copper pyrites, admit of the conjecture that this alteration is not unfrequent.

Copper pyrites undergoes conversion into sulphide of copper. Sillem† describes crystals of copper pyrites, coated with sulphide of copper, which are sharp at the edges, though the faces of the copper pyrites nuclei are corroded. Websky‡ also observed in the copper lodes at Kupferberg, in Silesia, such an alteration, not only of the copper pyrites, but also of the variegated pyrites into sulphide of copper and covellite. These ores present fine cracks, filled with hydrated oxide of iron. When this is removed by hydrochloric acid, thin crystalline crusts of sulphide of copper and covellite become recognizable. Oppe§ found, in an iron-stone vein, nodules of copper pyrites, imbedded in hornstone and quartz, with a crust of sulphide of copper round them.

The conversion of copper pyrites into iron pyrites or into covellite and sulphide of copper, are remarkable changes; because in the former case sulphide of copper must be removed, while in the latter sulphide of iron must be removed. That the removal of one or other sulphide from copper pyrites is effected by oxidation, is shown by other pseudomorphs of covellite after copper pyrites, in which the latter is fissured in all directions, the fissures being lined with covellite, while the intermediate mass is converted into iron ochre. Not unfrequently the nucleus of such masses still consists of copper pyrites.

Although these and all analogous alterations show that the constituents of metallic sulphides are removed only by oxidation, it still remains a question why sulphide of copper should be oxidized in one case, and sulphide of iron in another.

* Blum.—Nachtrag, p. 116.
† n. Jahrb. für Mineral, 1851, p. 337.
‡ Zeitschrift d. deutschen. geol. Ges. v, 425.
§ Cotta.—Gangstudien, ii, 167.

The conversion of copper pyrites into tile ore is shown by the abundant occurrence of pseudomorphous tile ore.* Websky also observed, in the above-mentioned lodes, the conversion of variegated copper pyrites into tile ore, and into iron ochre, mixed with red oxide of copper. In other instances, copper pyrites is converted into a compact, green, splintery silicate of copper. Sulphide of copper also undergoes conversion into silicate of copper, coloured by red oxide of copper.

All these products of alteration occupy precisely the same space as the original ores; and in this respect, are distinguished from the silicates of copper that have been deposited from water as blue translucent crusts similar to allophane, gradually becoming earthy at the surface, and passing into a meal consisting almost entirely of silica.

The copper lodes at Kupferberg are situated chiefly in dioritic slate. The adjoining rock is generally converted to some extent into masses resembling clayslate, serpentine, and chlorite. Alkaline silicates must therefore have been carried into the lodes, so as to decompose the sulphate of copper originating from the oxidation of the cupreous minerals, and give rise to silicate of copper. Websky remarks, that the occurrence of this substance is almost always connected with the absence of the iron belonging to the tile ore. This may be owing to the production of soluble double salts by the combination of the sulphate of potash, resulting from the above decomposition, with the sulphate of iron produced in the oxidation of the copper pyrites or variegated pyrites.

These lodes not unfrequently contain malachite in cavities of quartz, and sometimes it alternates with crusts of silicate of copper, that are sometimes more recent and sometimes older. This shows that alkaline carbonates, also originating from the decomposition of felspar, have effected the decomposition of sulphate of copper, producing carbonate of copper that was removed by water together with the silicate of copper.

The conversion of copper pyrites into malachite will be treated of subsequently.

It often happens that oxidized compounds of copper occur at the out crop and upper portions of lodes, while, at greater depths, there are only sulphuretted compounds.

Sulphide of lead occurs as galena in lodes situated in both the older and more recent strata, and is one of the most frequent ores, next to those of iron. Its occurrence as beds in carboniferous sandstone, variegated sandstone, limestone, keuper-sandstone, marl, and gypsum, lias sandstone and marl, in loam, and clay iron-stone, is especially remarkable, as well as its occurrence as stalactitic masses, as films upon coal, and filling cracks in coal, sphærosiderite, and fossil trees.

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* Blum.—Op. cit., p. 213—Nachtrag, p. 114.

It is a protosulphide, and very often contains silver. It sometimes contains free sulphur and that of Przibram, in Bohemia, from 2·2 to 3·6 per cent. zinc. The compact sulphide of lead at the Bockswiese, near Clausthal, contains 3·34 per cent. sulphide of zinc together with minute quantities of the sulphides of iron and antimony. Generally speaking, sulphide of lead presents but little tendency to combine with other electropositive sulphides.

Galena is susceptible of various kinds of alterations, and it also occurs as a product of the decomposition of bournonite. Sulphate of lead also occurs pseudomorphous after galena; carbonate of lead still more frequently; red oxide of lead, pyromorphite, and molybdate of lead, but seldom.

The conversion of galena into sulphate of lead is one of those rare cases in which the oxidation which sulphides undergo, is rendered recognizable by the pseudomorphous condition of the product, by reason of its slight solubility.

In the conversion of galena into carbonate of lead, the increase of weight amounts to 11·58, and the increase of volume to 28·13. It therefore becomes a question, how this alteration has taken place,* if there has not been anything removed from the lodes to make place for the carbonate of lead produced. The pseudomorphs of Markirchen are hollow and either lined with crystals of carbonate of lead, or a mixture of it with galena. In both cases therefore large quantities of the carbonate of lead must have been removed by water. Since carbonate of lead very frequently occurs in cavities and fissures in galena, and in this case has undoubtedly been produced on the spot, there would have been at least 11·58 parts by weight, or 28·13 parts by volume removed, even if the cavities were quite filled with carbonate of lead. When such alteration is going on, the water must contain carbonate of lead in solution; and this is shown to be the case, by the occurrence of carbonate of lead in cavities of brown hematite and quartz in galena lodes, in fissures and cavities in rocks. The conversion of galena into carbonate of lead presupposes that a very large quantity of water is brought in contact with it, in order to effect the oxidation of the lead and sulphur; and, since carbonate of lead is to some extent soluble, it would be removed by water. If the production of carbonate of lead is preceded by the production of sulphate of lead, a portion of this would also be removed in solution by water, since it dissolves in 2,2816 parts water.

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* Burkart.—Reisen in Mexico, ii. 167.

The conversion of galena into red oxide of lead commences at the edges of the crystals, and extends along the planes of lamination to the interior.[*] In this alteration the diminution of weight would be 4·52, and the increase of volume is 55·7. The description of these pseudomorphs does not indicate any such increase of volume; but on the contrary the galena becomes porous at the commencement of the alteration. According to these indications a considerable portion of the galena must be removed during the oxidation, either as sulphate or as carbonate.

As to the conversion of galena into pyromorphite, which occurs pseudomorphous after it, little can be determined with certainty, owing to the variable composition of that mineral. But since the oxygen, chlorine, phosphoric acid, and arsenic, that would enter into the composition of this mineral, amount to much more than the sulphur eliminated from the galena, there would certainly be an increase of weight, and there would also be, in consequence of the reduced density, an increase of bulk amounting to 6 per cent. The pseudomorphs, described by Zippe,[†] are partly hollow, and partly filled with galena. Blum describes pseudomorphs of this kind as being solid, and consisting either entirely of pyromorphite or of a mixture of it with galena.

There is only one known instance of the production of galena by the alteration of another lead compound—bournonite, and only a single known instance of galena being pseudomorphous after another mineral—pyromorphite. The latter is also the only instance of a metallic sulphide being pseudomorphous after a metallic salt.

Quartz, brown hematite, and siliceous oxide of zinc, occur as displacement pseudomorphs after galena. In the decomposition of galena its form seems sometimes to have been retained by the deposition of a coating of brown hematite upon the crystals, prior to the conversion into carbonate of lead. Blum [‡] mentions also the occurrence of hollow pseudomorphs consisting of brown hematite after galena, in a lode near Markirchen, in Alsace. In the Saxon Ergzebirge [§] there are pseudomorphs of grey copper ore after galena, presenting indications of very considerable reduction of volume; and a pseudomorphous mass of compact sulphide of copper and variegated pyrites after galena. Neither grey copper ore nor sulphide of copper contain sulphide of lead, so that in these instances there must have been a displacement of the galena.

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[*] Blum.—Op. cit. p. 176.

[†] Ibid., p. 181, and Nachtrag, p. 96.

[‡] Op. cit., p. 295.

[§] Breithaupt.—Paragenesis, etc., p. 184.

Sulphide of Nicklel occurs in lodes together with iron pyrites, etc. It is a protosulphide.

Sulphide of Cobalt occurs in lodes with copper pyrites, iron pyrites, galena, etc., and in beds in gneiss. It is a sesquisulphide.

Sulphide of Bismuth occurs in lodes and beds in the older rocks, together with ores of arsenic, copper, iron and lead, etc. It is a tersulphide.

Sulphide of Cadmium occurs as greenockite in cavities and fissures of amygdaloid rocks, at Bishopton, near Glasgow, and at Kilpatrick. It is a protosulphide.

Sulphide of Mercury occurs as cinnabar, in beds, and disseminated through rocks, more rarely in lodes accompanied by metallic mercury, subchloride of mercury, amalgam, etc. It is a protosulphide. It seems to occur generally in schistose rocks. At Idria and Almaden it is disseminated through slate and limestone, and also occurs as a film upon quartz veins. It occurs very frequently in the coal measures of Rhenish Bavaria, though not in such quantity as to be worth working; also as veins and threads in a clay resulting from the decomposition of porphyry at la Loma del Encinal, in Mexico, in sandstone, situated between clay and calcareous breccia at Santa Barbara, in Peru, in beds of sand and clay in Connecticut, and in the alluvial deposits of the Ural.

Blum[*] describes pseudomorphous cinnabar after grey copper ore from Moschel-Landsberg, and regards it as a displacement pseudomorph. The occurrence of hepatic cinnabar at Idria in a bituminous shale, shows that organic substances have had something to do with the production of cinnabar.

Cinnabar occurs pseudomorphous after iron pyrites.[†] Domeyko[‡] states that in all the mercury mines of Chili, the ores of mercury are accompanied by a substance containing a highly mercurial grey copper ore, and a fine pale red powder said to consist of antimoniate of mercury. This is probably a product of the decomposition of the grey copper ore, especially since there is also some blue carbonate of copper present.

Sulphide of silver occurs in lodes together with metallic silver,

[*] Op. cit.—2ter Nachtrag, p. 124.

[†] Ibid, p. 123.

[‡] Ann. des Mines (4) vi, 183.

red silver ore, galena, etc. The pure protosulphide of silver is of frequent occurrence. It also occurs as a product of the decomposition of red silver ore. It is sometimes coated with white iron pyrites, or iron pyrites, and sometimes there is a cavity between these crusts and the nucleus of sulphide of silver. In a few instances the latter has been entirely removed.*

Sulphide of tin does not occur alone as a mineral, but only in combination with other sulphides.

Sulphide of molybdenum occurs in lodes and beds of magnetic iron ore and tin stone, in granite, syenite, gneiss, mica-slate, chlorite-slate, and talc-slate ; in quartz veins in granite, and gneiss; in the cupreous slate of Mansfeld.† It is a bisulphide. The sulphide of molybdenum of Lindas in Smaland, and of Bohuslän, contains small traces of phosphoric acid.

Sulphide of antimony occurs in lodes in gneiss, mica-slate, granite, diorite, syenite, porphyry, clay-slate, grauwacke, and transition limestone. It is generally a tersulphide, and sometims contains traces of arsenic and iron. This is the most frequent ore of antimony, and the ore from which others have originated.

Sulphide of arsenic occurs as realgar and orpiment in lodes, accompanied by metallic arsenic, ores of silver, copper, and lead, in dolomite, limestone, and granular gypsum, in the solfatara of Puzzuoli, and in the masses thrown out of Vesuvius, &c. Realgar is a bisulphide, and orpiment a tersulphide. Volger ‡ regards orpiment as being in all cases a product of the alteration of realgar. This alteration takes place very readily, and even the specimens of realgar in mineral collections gradually crumble into a yellowish red powder, arsenous acid being produced as small crystals, while another portion of the bisulphide combines with the sulphur thus eliminated, and produces tersulphide.

The dimorphine occurring in fissures of the rocks at the large solfatara, in Italy, and generally associated with realgar is a sulphide of arsenic, containing 24·55 per cent. sulphur.§

Compound sulphides.—Sulphide of silver and copper occurs together with sulphide of silver, copper pyrites, galena, sulphide of copper, variegated copper pyrites, malachite, etc. It consists of equal equivalents of the two sulphides. In the compact ore of Chili, the two sulphides are associated in very varying proportions.

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* Blum.—Op. cit. 2^{ter} Nachtrag, p. 120.

† Poggend. Annal. li, 103.

‡ Studien zur Entwicklungsgeschichte der Mineralien, p. 35, et seq.

§ Zeitschr. d. deutsch. geol. Ges. iv, 173.

Cuproplumbite consists of one equivalent sulphide of copper, partially replaced by sulphide of silver, and two equivalents sulphide of lead.

Corrolite, a white mineral from Flinksburg, consists of equal equivalents of sulphides of copper and cobalt, with some nickel and arsenic, probably owing to an admixture of white cobalt ore, or arsenical cobalt.

Cupreous sulphide of bismuth occurs in a lode traversing granite, with metallic bismuth and copper pyrites; also in cobalt lodes. It consists of sulphides of copper and bismuth.

Sulphide of bismuth and lead, containing some sulphide of copper, occurs as needle ore near chiviatite, together with iron pyrites, at Chiviato, in Peru.

Sulphides of nickel and bismuth, containing also cobalt, iron, copper, and lead, occur, together with quartz and copper pyrites, at Grünau, but the mineral does not appear to have a definite composition.

Red silver ore occurs in lodes traversing the older rocks, associated with galena and sulphide of silver. The dark variety contains antimony. The pale coloured variety at Andreasberg appears to contain both antimony and arsenic. The calculated composition of this mineral is—

	Dark variety.	Pale variety.
Sulphide of silver	67·76	75·11
„ antimony	32·24	....
„ arsenic	....	24·89
	100·00	100·00

Sulphide of silver occurs pseudomorphous after red silver ore, the alteration being recognizable in all stages.*

In the case of the dark coloured variety, the reduction of weight would be 32·24, and in that of the pale coloured variety 24·89; the diminution of volume about 45·30 in the former, and 39·38 in the latter. In this alteration there would be 23·46 parts antimony, or 15·16 parts arsenic, removed, together with some sulphur.

Iron pyrites and radiated pyrites occur as pseudomorphs after red silver ore at Joachimsthal. The latter are sometimes so sharply defined, that they might be taken for real crystals; but some are hollow, and still contain remains of red silver ore. Radiated pyrites is almost always associated with the pale coloured variety of red silver ore, and the nodular masses of it often contain a nucleus of red silver ore.

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* Marx.—Jahrb. der Chem. und Phys. lvi.—Blum. op. cit. p. 21.—Sillem & Reuss. 2ter Nachtrag, p. 10.

Brittle sulphide of silver occurs in lodes, traversing the older rocks, together with other silver ores, galena, blende, etc. Its calculated composition is—

Sulphide of silver	80·79
„ antimony	19·21
	100·00

No instances of the decomposition of this mineral are known; but iron pyrites and radiated pyrites occur pseudomorphous after it, the former at Joachimsthal, in Bohemia. Blum considers that the six-sided prisms, consisting of sulphide of iron, in the lodes at Freiberg, are instances of the latter kind of pseudomorphs. Sometimes the same pseudomorphs consist partly of iron pyrites and partly of radiated pyrites. They are granular at the interior, and are sometimes hollow.*

These facts are very interesting because they show that sulphide of silver is capable of being removed by water as well as the sulphide of antimony, in the alteration of red silver ore.

Miargyrite consists of equal equivalents of the sulphides of antimony and silver, with some copper and iron. It occurs at Braunsdorf in Saxony, and in Mexico.

Sternbergite appears to consist of sulphide of silver and two equivalents sesquisulphide of iron. It occurs together with red silver ore, brittle sulphide of silver, and other silver ores.

Xanthokon, from the Himmelsfürst mine, near Freiberg, consists of—

3 equivalents sulphide of silver	72·75
2 „ bisulphide of arsenic	27·25
	100·00

Enargite is a compound of the sulphides of copper, antimony, iron, zinc, silver, etc., with sulphide of arsenic. It occurs in considerable masses in a lode traversing crystalline limestone at Morosocha, in the Peruvian Cordilleras.

Cupreous sulphide of antimony occurs together with sulphide of antimony, bournonite, zinkenite, and plagionite, in a quartz vein in the Harz. It consists of equal equivalents of the sulphides of antimony and copper, with small quantities of iron and lead.

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* Blum.—Op. cit., p. 300.

Zinkenite consists of equal equivalents of the sulphides of antimony and lead, with small quantities of iron, copper, and silver. It occurs in the antimony mines of Wolfsberg, in the Harz.

Plagionite consists of three equivalents sulphide of antimony, and four equivalents sulphide of lead. It occurs with bournonite, tinder ore and feather ore, at Wolfsberg.

Jamesonite consists of two equivalents sulphide of antimony, and three equivalents sulphide of lead, with small quantities of iron and copper. It occurs together with bournonite.

Feather ore consists of sulphide of antimony, and two equivalents sulphide of lead, with small quantities of iron and zinc. It occurs with other antimonial ores at Wolfsberg. Heteromorphite is a variety of feather ore.

Steinmanite occurs at Przibram, in Bohemia, and is said to consist of the sulphides of antimony and lead. The decomposed mineral is mixed with iron pyrites, crystalline carbonate of lead and capillary metallic silver.

Boulangerite consists of sulphide of antimony, and three equivalents sulphide of lead, with some sulphide of copper, zinc, and iron. It occurs together with iron pyrites, arsenical pyrites, and sulphide of antimony.

Kilbrikenite appears to consist of sulphide of antimony and five equivalents sulphide of lead.

Grokronite is essentially a compound of the sulphide of antimony, of lead and arsenic, but contains small quantities of copper, iron, zinc, silver, and bismuth.

Berthierite consists of the sulphides of antimony and iron in three different proportions, and sometimes contains small quantities of zinc, arsenic, and manganese. It occurs together with iron pyrites and sulphide of antimony in lodes.

Bournonite consists of the sulphides of antimony, lead, and copper, the latter in varying proportions. It occurs together with sulphide of antimony, galena, grey copper ore, etc. It never contains silver unless it is mixed with grey copper ore. The pseudomorphous galena after bournonite, is evidence of an alteration in which the sulphide of antimony and copper were removed, while the sulphide of lead remained as thin crusts.* If none of the sulphide of lead was removed it would amount to from 46·26 to 49·54 parts, consequently the diminution of weight would be from 53·74 to 50·46, and the diminution of volume from 58·18 to

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* Sillem.—Poggend. Annal., lxx, 570. Blum.—Op. cit., 2ter Nachtrag, p. 14.

60·73, corresponding with the porous condition of the pseudomorphs.

Sulphide of silver, lead, and antimony is of rare occurrence. It appears to be argentiferous bournonite. Brongniardite is a similar compound, resembling heteromorphite.

Mispickel consists of protoarsenide of iron and bisulphide of iron. Sometimes a portion of the iron is replaced by cobalt, as in the cobaltic mispickel of Skutterud, in Norway. It occurs in lodes and beds, or disseminated through some rocks.

Iron pyrites occurs pseudomorphous after mispickel.[*]

Blum remarks that if, in this alteration, only the arsenide of iron was removed, the residual sulphide of iron would show this by the porosity of the crystals. Plattner and Götzschmann[†] describe a lode near Freiberg, which contains baryta-spar, quartz, zincblende, mispickel, iron pyrites, copper pyrites, and some galena. The adjoining gneiss rock is converted, for a distance of from two to six feet from the lode, into a white, hydrated clay, with numerous laminæ of mica, and crystals or fragments of mispickel, with a nucleus consisting of zincblende, or a mixture of it with mispickel and galena. The mispickel is so minutely disseminated through this clay, that at some places it appears to constitute a cementing material. The decomposed state of the rock is most considerable near the surface, and the size of the mispickel crystals is greater there than at lower parts of the lode.

Plattner considers that in this decomposed mass there has been a production of mispickel, by the reaction of sulphates and arsenous acid with organic substance, derived from the decayed timbering of the mine. The working of this mine may extend back to 1530, or perhaps even to the thirteenth century.

Arsenical sulphide of cobalt occurs in beds in gneiss and mica-slate, and in lodes traversing clay-slate. It consists of—

	I.	II.	III.	IV.
Sulphur	19·1	20·8	19·08	20·00
Arsenic	43·0	44·8	42·53	43·14
Cobalt	29·8	33·1	8·67	9·62
Iron	3·2	6·4	20·99	28·03
Antimony	..	..	1·04	2·84
Copper	..	..	..	2·36
	..	..	..	..

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[*] Blum.—Op. cit., p. 14.

[†] Jahrb. f. den Berg—und Hüttenmann, 1851, p. 32.

Arsenical sulphide of nickel occurs together with other nickel and cobalt ores. The maximum and minimum amounts of its constituents are—

Sulphur	18·83	20·16
Arsenic	44·01	48·02
Nickel	29·94	33·04
Iron	4·11	6·00
	....	....

Antimonial sulphide of nickel occurs together with arsenate of nickel, and in lodes of hematite and galena. Its composition is somewhat variable, and it sometimes contains arsenic. The arsenate of nickel is probably a product of decomposition.

Antimonial sulphide of copper occurs in iron-spar lodes, together with iron pyrites and galena, etc., in Carinthia. It consists of sulphur, antimony, arsenic, lead, copper, and iron.

Grey copper ore occurs in lodes and beds in various rocks, together with copper pyrites, iron pyrites, galena, blende, iron-spar, etc. The maximum and minimum amounts of its constituents are given below, and in column I the number of times the several constituents were detected in thirty six analyses.

	I.	II.	
		Maximum.	Minimum.
Sulphur	36	27·25	19·38
Antimony	34	34·09	12·46
Arsenic	13	10·19	..
Copper	36	48·00	14·8
Iron	36	9·46	0·86
Zinc	21	7·29	
Silver	30	31·29	
Mercury	10	16·69	
Lead	4	1·75	

Among the electro-negative constituents, sulphur and antimony are always present; and copper and iron among the electro-positive constituents. Lead must be regarded as accidental, owing to an admixture of galena. Zinc* also may be due to an admixture of blende. Silver, though its amount varies very much, may, perhaps, be an essential constituent.

Since grey copper ore undergoes conversion into malachite, blue carbonate of copper, copper pyrites, and tile ore,—sulphur, antimony, and arsenic would be eliminated, as well as other electro-positive metals; iron would remain only in the conversion into tile ore. If the alteration is effected by oxidation, the sulphuric acid, antimonial and arsenical acids produced, would find but small quantities of bases for saturation, so that the greater part would be removed in a free state. At Wolfach, grey copper is accompanied by oxide of antimony, and at Magurka, in Hungary, by antimony ochre.

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* According to Gueymard and Ebelmen, the grey copper ore of Chapeau and Champoléon contains traces of platinum.

Tennantite occurs in copper lodes. It is an arsenical grey copper ore, sometimes containing traces of silver or lead.

Polybasite consists of sulphur, antimony, arsenic, silver, and copper, in varying proportions, with a little iron and zinc. It occurs together with red silver ore, sulphide of silver, metallic copper and silver.

Sulphide of tin occurs in lodes, with copper pyrites, at St. Agnes and other places in Cornwall. It consists of the sulphides of tin, copper, zinc, iron, and lead, and is probably a compound of sesquisulphide of tin with copper pyrites, and an admixture of zincblende in various proportions.

Sulphide of nickel and iron occurs, with copper pyrites and magnetic pyrites, in a lode traversing hornblende rock. It consists of the sulphides of iron, copper, and nickel.

D.—SELENIDES.

Selenide of copper occurs at Smaland and at Lerbach, in the Harz.

Selenide of lead occurs in lodes at Clausthal, Zorge, Tilkerode, in the Harz. It has never been found associated with galena. It is a protoselenide, and sometimes contains some cobalt.

Selenide of silver has not yet been met with in a pure state, but only in combination with selenide of lead. At Tasco, in Mexico, a biselenide of silver is said to occur.

Selenide of silver and lead occurs at Tilkerode. It contains—

		Rose.	Rammelsberg.
Selenide of silver	....	93·21	15·94
„ lead	....	6·79	83·82

The selenide of silver and molybdenum, described by Breithaupt, contains some gold.

Selenide of silver and copper occurs, accompanied by selenide of copper.

Selenide of lead and copper consists chiefly of selenide of lead, and contains small quantities of silver and iron.

Selenide of mercury occurs, mixed with quartz, at Clausthal, and consists of five equivalents selenium, and six of mercury.

Selenide of mercury and silver occurs, mixed with selenide of lead, at Tilkerode.

Selenide and sulphide of mercury, combined in the proportion of four equivalents of the latter to one of the former, occurs together with metallic mercury and sulphur at San Onofre, in Mexico.

At Calebras, in Mexico, there is a mineral consisting of selenide of zinc and sulphide of mercury, and another consisting of selenium mixed with selenide and sulphide of mercury, selenide of cadmium and iron.

Selenide of cobalt and lead appears to consist of six equivalents selenide of lead and one equivalent selenide of cobalt.

With the exception of the above-mentioned instance, selenium is not known to occur native; but the chloride of ammonium at Vulcano contains some sulphide of selenium. There are also small quantities of selenium in the iron pyrites of various localities, in some copper pyrites, tile ore, pitchblende, galena, and tellurium ores. It would appear, therefore, that selenium is frequently associated with sulphur, though in extremely minute proportion.

E.—ANTIMONIDES AND ARSENIDES.

Antimonide of nickel occurs only in lodes at Andreasberg, in the Harz, accompanied by arsenical cobalt ore and galena. It is a diantimonide, with a small quantity of iron.

Antimonide of silver occurs in lodes traversing the older rocks.

Arsenide of antimony occurs in lodes traversing gneiss, together with metallic antimony, sulphide of antimony, antimony ochre, arsenate of antimony, and arsenical cobalt ore. It consists of three equivalents arsenic, and one equivalent antimony.

Arsenide of iron occurs in iron-spar lodes, in serpentine, etc. It is a binarsenide, part of the iron being sometimes replaced by cobalt and nickel, and sometimes it is mixed with mispickel.

Arsenide of manganese occurs in Saxony, as a protarsenide.

Arsenide of copper.—Condurrite consists of oxide of copper, arsenous acid, sulphur, arsenic and water, and is a mixture of arsenite of copper, sulphide of copper, and arsenide of copper.

The arsenide of copper at Calabazo contains 71·15 per cent. copper, and 28·85 arsenic.

Binarsenide of nickel occurs with other nickel and cobalt ores. Nickel ores are more susceptible of decomposition than cobalt ores, and the binarsenide most of all.

Protarsenide of nickel occurs together with cobalt and silver ores in lodes, and contains small quantities of iron, lead, antimony, cobalt, copper, and sulphur. This mineral is also susceptible of oxidation and conversion into nickel ochre, like the previous one.

It is remarkable, that in the oxidation of arsenides of nickel, a basic arsenate is always produced, although in both ores of this kind there is such a large excess of arsenic. If, in the oxidation, more arsenic acid were produced than would be sufficient to produce nickel ochre, this substance would be removed, owing to its solubility in excess of the acid. Most likely the excess of arsenic above what is requisite for producing basic arsenate is only converted into arsenous acid.

Arsenide of cobalt occurs in lodes with ores of silver, copper, nickel, etc.; but Breithaupt found that the arsenical cobalt of Schneeberg is essentially arsenide of nickel, and G. Rose[*] found that all the crystallized arsenical cobalt ore in the Berlin mineral collection contains nickel. The following analyses of the crystallized arsenical cobalt ore of Riechelsdorf show, moreover, that the proportions are not constant:—

	I. Sartorius.	II. Bull.	III. Klaüer.	IV. Weber.	V. Rammelsberg.
Arsenic	73·53	76·09	68·78	59·38	60·42
Nickel	14·06	12·25	12·15	19·38	25·87
Cobalt	9·17	4·56	16·37	18·30	10·80
Iron	2·24	6·82	2·30	0·72	0·80
Copper	..	..	0·45	..	..
Sulphur	0·94	..	..	2·22	2·11
	99·94	99·72	100·00	100·00	100·00

Arsenical cobalt ore is converted by oxidation into arsenate of cobalt. Kersten's[†] observations seem to show that it is the only cobalt ore that undergoes this alteration. Blum[‡] found arsenate of cobalt with the form of arsenical cobalt ore in a specimen from Riechelsdorf. The cobalt ores occur at this place accompanied by arsenical nickel ore and nickel ochre. A part of the altered crystals present the peach-blossom colour of arsenate of cobalt; sometimes, also, it is brownish red while the remainder is green. Since, according to Kersten, the peach-coloured arsenate of cobalt is hydrated, while the green variety is anhydrous and contains protoxide of iron, it would seem that both salts were produced by the oxidation of the arsenical cobalt ore. It does not appear, however, what has become of the nickel and the corresponding amount of arsenic acid, unless, perhaps, the green substance in the above pseudomorphs consists of arsenate of nickel.

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[*] Mineral system, p. 50.

[†] Poggend. Annal., lx, 251.

[‡] Op. cit. p. 212.

Kersten did not find any nickel, or at most mere traces, in any of the arsenate of cobalt occurring in the Saxon highlands; consequently, nickel and arsenic must have been removed during the conversion of the arsenical cobalt ore into arsenate of cobalt. In No. IV, which contains most nickel and cobalt, the latter metal would require 23·88 parts arsenic acid, and the nickel would require 25·38 parts, or altogether 49·26 parts arsenic acid; but the 59·38 per cent. arsenic in this mineral would furnish 91·03 parts arsenic acid, nearly twice as much as would be requisite for the saturation of the oxides of cobalt and nickel. This would be still more the case with the other specimens of arsenical cobalt ore.

The coating upon arsenical cobalt ore consists, according to Kersten, of a mixture of arsenous acid with a smaller proportion of arsenate of cobalt and water, apparently in the same proportions as in cobalt bloom. It is much more frequently met with than the cobalt bloom, and appears to be the first product of the decomposition of the arsenical cobalt ore. It appears, indeed, that in the decomposition of arsenical cobalt ore part of the arsenic is converted into arsenous acid, and that the remainder is converted into basic arsenates of cobalt and nickel.

Terarsenide of cobalt occurs in the mines at Skutterud, in Norway. It does not contain nickel.

A mineral analogous to the above, and containing bismuth, occurs together with sulphide of bismuth, and is probably a mixture of terarsenide of cobalt and sulphide of bismuth.

F.—TELLURIDES.

Telluride of silver occurs as nests in talc-slate, very abundantly in the Altai, at the Kolywan mines, in Siberia, and with other tellurium ores at Nagyag, in Transylvania. It is a prototelluride, sometimes containing traces of iron, copper, and gold. At the last-named locality there are two kinds of ores, one containing 0·69 and the other 18·26 per cent. of gold in the place of equivalent quantities of silver.

Telluride of lead occurs as small patches, with the telluride of silver, in the Altai. It appears to be a prototelluride, mixed with telluride of silver.

Telluride of bismuth occurs as tetradymite, at Deutsch-Pilsen, in Hungary, in a decomposed porphyry; at Schemnitz, S. Joec, in Brazil, at White Hall, in Virginia, in mica-slate, and as nodules covered with oxide of bismuth, upon quartz, with gold between the laminæ; and in Davidson County, N. Carolina, on a quartz vein, with gold. It consists essentially of tellurium and bismuth, with small quantities of sulphur and selenium,* but does not seem to be a definite compound.

Telluride of gold and silver occurs as graphic tellurium, together with metallic gold and other tellurium ores, in narrow lodes traversing the porphyry at Offenbanya, and rarely at Nagyag, in Transylvania. It is essentially a tertelluride of gold, in which gold is partially replaced by silver, and it also contains small quantities of copper, iron, lead, antimony, sulphur, and arsenic.

Telluride of lead occurs as black tellurium in lodes at Nagyag and Offenbanya. It consists essentially of lead and tellurium, but contains gold, sulphur, copper, and minute traces of silver and antimony. It is most likely a mixture.

G.—TITANATES.

Titanate of iron occurs as iserine very frequently in basalt, dolerite, and lava, and in many instances, the presence of titanic acid in basalt has been overlooked in the analyses. The magnetic iron ore of Dannemora was found by Kersten to contain 0·25 per cent., and that in the chlorite-slate of the Tyrol 3·31 per cent. titanic acid. Iserine generally contains small quantities of silica, lime, magnesia, and oxide of chromium; one variety also contains 3·6 zinc and another ytteria and cerium. Since the proportions of titanic acid, protoxide of iron, and peroxide of iron in the several varieties of this mineral vary so much, no formula can be devised to represent its constitution. If the prototitanate of iron resembles other protosalts of iron in being converted by oxidation into hydrated peroxide and basic salts of the peroxide, this compound would have undergone a variety of changes in the course of time. In the production of basic salts, titanic acid would be eliminated, and the titanic acid in form of rutile probably originates from this source. If at the same time the tendency to the production of magnetic iron ore came into force, this substance would be added to the other products of oxidation, and the magnetic character of some varieties of titanite of iron seems to indicate that this is really the case.*

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* Bericht üb. die 21 Versamml. deutsch. Naturforscher, p. 195. Sillim. Amer. Journ. (2) vii, 282, x, 78.—Chem. pharm. Centralblatt, 1852, p. 72.—Jahrb. für Mineral., etc., 1852, p. 698.

Titanate and silicate of lime occurs as titanite or sphene, either imbedded, or in cavities of gneiss, mica-slate, chlorite-slate, granite, syenite, diorite, trachyte, phonolite, basalt, the glassy felspar rock at the lake of Laach, in granular limestone, and deposits of ore. It consists of three equivalents of titanic acid, two equivalents of silica, and three equivalents of lime. Greenovite is a variety of titanite, containing manganese.

Titanate of lime occurs as rutherfordite in the gold mines of Rutherford Co., North Carolina, and combined with silicate of protoxide of iron and lime as schorlamite, together with arkanite and ozarkite, at Magnet cave, Hot Springs Co., Arkansas.

Titanate of yttria occurs combined with a silicate of alumina, iron, and lime, as yttrotitanite, in a felspar quarry at Buön, near Arendal.

Titanate of zerconia occurs combined with hydrated silicate of lime, magnesia, and protoxide of iron, as oerstedite on the augite at Arendal. It contains traces of tin.

The polymignite in the zircon-syenite of Fredirkswarn, in Norway, contains titanic acid, zirconia, peroxide of iron, lime, oxides of manganese, cerium, and yttrium, with traces of potash, magnesia, silica, and oxide of tin.

The œschynite in the granite at Miask contains, according to Hermann's analysis, titanic and niobic acid, combined with the oxides of cerium and lanthanium, protoxide of iron, and yttria.

The euxenite of Toedestrand, in Norway, is a hydrated compound of yttria, and protoxides of uranium, cerium, and iron, with titanic and tantalic acids.

Small quantities of titanic acid exist in silicates, and together with other metallic acids in several minerals; but it is uncertain what bases it is combined with. Some kinds of chrysoberyll contain from 1 to 2·67 per cent, the tachylite in the basalt of the Vogelsgebirge contains 1·4, and tschewkinite, 1·65 per cent. Small quantities of titanic acid also occur in rocks, as for instance the basalt, serpentine, and lava of Iceland, to the extent of 3·73 per cent. Clay-slate sometimes contains traces.

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* Hunt.—Silliman's Amer. Journ. xiv, 344.

H.—TANTALATES, NIOBATES, AND PELOPATES.

Compounds of tantalic acid without niobic or pelopic acids, occur in the tantalite of Finland and Sweden, as well as in the yttrotantalite of Ytterby, in Sweden. The columbite or niobite of Bodenmais, in Bavaria, and of Massachusetts, and the samarskite of the Ilmen mountains on the contrary contain all three acids.*

The tantalite of the granite and in dykes of albitic granite in Finland and Sweden contains—

Tantalic acid	from	77·83	to	84·70	per cent.
Protoxide of iron	„	8·47	„	14·68	„
„ manganese	„	0·90	„	4·89	„
Oxide of copper	„	0·04	„	1·81	„
„ tin	„	0·32	„	6·81	„
Lime	„	0·07	„	0·50	„

As the amount of tantalic acid diminishes in proportion as that of oxide of tin increases, the latter might be regarded as an acid, but Berzelius considers that tantalite occurs only mixed with tin ore, which in the tantalite of Finbo amounts to from 17 to 84 per cent., while there are varieties of tin ore that are highly tantaliferous.

The columbite of the granite at Bodenmais and of Middletown in Connecticut contains:—

Tantalic acid †	from	78·83	to	81·34	per cent.
Protoxide of iron	„	13·89	„	16·66	„
„ manganese	„	3·77	„	4·77	„
Oxide of copper	„	0·06	„	1·50	„
„ tin	„	0·12	„	0·47	„
Lime	„	....	„	traces.	„

That of Haddam ‡ comes between these extremes; that of the Ilmen mountains approximates to it, but contains also 3·01 per cent. magnesia, and 0·56 protoxide of uranium. The tantalite of Limoges, and that in the pegmaite of Tirschenreuth, in Bavaria,* differs more or less in composition from this.

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* Poggend. Annal. lxiii, 335, and lxix, 119.

† This comprises all three acids.

‡ Hunt.—Sillim. Amer. Journ. (2), lxiv, 340.

Yttro-tantalite occurs in beds of felspar in the gneiss at Finbo, Ytterby and Kararfvet in Sweden. The dark brownish black variety is a tantalate of lime and yttria, mixed with some tungstate of protoxide of iron.

The black variety has the same composition, but is mixed with much more tungstate of iron. The yellow variety is tantalate of yttria and oxide of uranium, with 1·4 per cent. magnesia, and 0·4 oxide of copper, The yttrotantalite of the Ilmen mountains, near Miask is a tantalate of yttria, lime, iron, manganese, and uranium, with small quantities of zirconia, oxides of cerium and lanthanium, titanic, and tungstic acids.

Samarskite occurs together with œschynite, imbedded in the felspar at Miask, and consists of

Tantalic acid	from	55·91	to	56·38	per cent.
Yttria	„	8·36	„	11·04	„
Lime and protoxide of manganese	„	0·92	„	1·88	„
Protoxide of iron	„	15·43	„	15·94	„
Oxide of uranium	„	14·16	„	16·77	„
Magnesia	„	0·75	„	0·80	„
Oxide of copper	„	traces.			

The bases are nearly the same as those in the yttrotantalite of the Ilmen mountains. Yttroilmenite is identical with this mineral.

Pyrochlor occurring in the granite of Miask, and the zircon-syenite, at Fredrisckwärn, Laurvig and Brevig, in Norway, contains lime, yttria, thoria, protoxides of iron and manganese, oxides of cerium, lanthanium, uranium, sodium, fluorine and tantalic acid, together with traces of titanic acid, oxide of tin, magnesia and water. The quantitative proportions of these constituents vary considerably. The acid obtained by Wöhler, from the pyrochlor of Miask, consisted chiefly of niobic acid, with some pelopic, tungstic and titanic acids. Among the compound tantalates, pyrochlor is the only one that contains so much as 7·4 per cent. of water. That of Massachusetts is essentially tantalate of lime.

The fergusonite imbedded in quartz and felspar at Kikertaursack, near Cape Farewell, in Greenland, contains tantalic acid, yttria, protoxide of cerium, zirconia, oxides of tin, uranium and iron. It is essentially tantalate of lime.

The wöhlerite in the zircon-syenite of some islands, near

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[*] Correspondenzblatt des zool. mineralog. Vereins zu Regensburg, 1852, p. 73.

Brevig, contains pelopic acid, silica, zirconia, lime, magnesia, protoxides of iron and manganese, and soda. It is a compound of pelopates and silicates.

The polycras of the granitic dykes in the norite at the island of Hitteroë, near Norway, contains niobic, pelopic and titanic acids; zirconia, yttria, protoxides of iron; uranium and cerium, together with traces of alumina, lime, and magnesia.

Euxenite has already been referred to.*

I. TUNGSTATES.

Tungstate of iron and manganese occurs as wolframite, chiefly with tin ore, in granite, talc-slate, quartz veins in gneiss, and grauwacke, sometimes accompanied by tungstate of lime and sulphide of molybdenum, etc. In Saxony, Bohemia, and Cornwall, it is constantly associated with tin ore, but it does not occur in alluvial deposits of tin ore; it is more susceptible of disintegration, both mechanically and chemically, than tin ore is. This is apparent even in lodes, where it is not unfrequently converted into tungstate of lime.† There are two varieties of this mineral, one of them consisting of tungstate of manganese, with four or perhaps five equivalents of tungstate of iron; the other consisting of three equivalents tungstate of manganese and two equivalents tungstate of iron. The brownish black colour of wolframite indicates that it is not a pure protosalt of iron, especially since prototungstate of manganese is white, and prototungstate of iron is green. Therefore, if the native compound was originally a protosalt, it would seem to have undergone oxidation, and to have lost part of the tungstic acid. Indeed, Schneider detected free tungstic acid in wolframite, but could not find peroxide of iron. Rammelsberg's analysis of acicular crystals of a brownish red mineral, passing into steinmark and traversed by fluorspar and apatite, shows that tungstic acid is to some extent removed by water. The quantity of tungstic acid requisite for the saturation of the protoxides of iron and manganese, is 17·79 more than that indicated by analyses. Then since the steinmark does not contain any tungstic acid, but contains peroxides of iron and manganese, the tungstic acid must have been removed. Hence it would appear, that by the peroxidation of the metals, the affinity of the acid for the bases is weakened.

The carpholite of the Schlackenwald contains nearly the same quantities of iron and manganese as the above brownish red mineral, but no tungstic acid, in the place of which there is silicate of alumina, amounting to two per cent. less than the tungstic acid. If, therefore, the tungstic acid in the brown mineral were replaced by silicate of alumina, it would be converted into carpholite, and the presence of 2·09 per cent. silicate of alumina in that mineral seems to indicate that this is really the ease.

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* See ante, p. 481.

Breithaupt.—Paragenesis, p. 141.

Sillem and Blum* describe varieties of wolframite that present very distinct indications of conversion into tungstate of lime. The change progresses from the exterior inwards; the scales, so characteristic of wolframite, consist of fine grained crystalline tungstate of lime. In Cornwall scheelite occurs together with brown iron ore and iron ochre, which are, perhaps, the products of the decomposition of the wolframite.

It is not difficult to account for this decomposition; for since tungstic acid is capable of displacing even the sulphuric acid of gypsum, its affinity for lime must be very considerable. Generally speaking, salts that are decomposed by any acid are also decomposed by the salts of that acid; and hence we might expect that the tungstic acid in wolframite would decompose sulphate of lime as well as free tungstic acid. If this be the case, water containing gypsum continually coming in contact with wolframite would give rise to a mutual decomposition, producing tungstate of lime and sulphate of iron and manganese. It is true gypsum does not occur in granite; but since wolframite occurs in lodes, together with mispickel, zinc, blende, galena, sulphides of antimony and copper, and iron pyrites, which yield sulphuric acid by oxidation, and since almost all water contains carbonate of lime, the conditions for the production of sulphate of lime would rarely be wanting in the neighbourhood of wolframite.

Wolframite contains nearly as much tungstic acid as scheelite, so that there would be but a slight diminution of weight in the conversion of one into the other, but an increase of volume to the extent of about 20 per cent. This does not correspond with the presence of cavities in the pseudomorphs of scheelite after wolframite, so that a portion of the products must have been removed by water during the alteration. Sillem † describes crystallized scheelite situated upon quartz, and between them a pseudomorph of quartz after wolframite, which would appear to indicate that it may be displaced by quartz, and removed by water, either directly or after decomposition.

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* Op. cit., 2ter Nachtrag. p. 67.

† Jahrb. für Mineral., etc., 1851, p. 395.

Gahn and Berzelius found tungstic acid in the tantalite of Broddbo, and considered it was in combination with protoxide of iron and manganese, which would accordingly make the amount of wolframite in the mineral 8·69. The quantity of tungstate of iron and manganese in yttrotantalite would amount to 10·7, if the tungstic acid is combined with these oxides; but it may be combined with lime.

Tungstate of lime occurs as scheelite in deposits of tin ore and magnetic oxide of iron, in deposits in granite and gneiss, lodes in grauwacke, etc. There are only two analyses that do not indicate the presence of foreign constituents; generally speaking, the mineral contains silica, peroxides of iron and manganese, oxides of copper and magnesia. Calculating from the analysis of the purest variety of scheelite, the quantities of tungstic acid requisite for saturating the lime in other varieties, it appears that they are always less than the actual quantities. Hence it may be inferred that this excess of acid is combined with the silica, provided this was not in the state of quartz, and perhaps with the other bases present. It is true that compounds of tungstic acid with other acids are not known, and therefore the possibility of its combining with silica is questionable. Breithaupt found from 2 to 3 per cent. of hydrofluoric acid and some hydrochloric acid in the scheelite of Zinnwald, which might perhaps exist in combination with tungsten.*

The following analyses refer to three specimens of scheelite that are remarkable for the large amount of foreign bases.

	I.	II.	III.
Tungstate of lime	89·98	83·89	87·74
„ protoxide of iron	4·33	..	..
„ „ manganese	1·25	..	..
„ copper	..	12·77	..
„ magnesia	..	..	4·38
Tungstic acid	1·19	0·44	5·82
Silica	2·54	0.75	..
	99·29	97·85	97·94

I. Yellowish grey scheelite of Huntington, Connecticut.

II. Green scheelite of Coquimbo, in Chili.

III. Yellow scheelite of Catharienburg.

The scheelite of Huntington is often accompanied by a coating of yellow oxide of tungsten, most likely tungstic acid that had been eleminated by the decomposition of the scheelite. This is probably the case with all yellow scheelite, since tungstate of lime is quite white. The only decomposing agent that can be supposed to have exercised this influence is carbonated water.

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* Schweigg. Jour. liv, 130.

The greyish white and grey varieties of scheelite may owe their colour to an admixture of tungstate of iron and manganese; the yellowish brown and brown varieties, to the decomposition of those salts.

Artificially prepared tungstate of lime is soluble in 100060 parts of water, therefore it may be inferred that the production of scheelite from lime salts occurring in minerals, is not improbable.

Blum* describes scheelite crystals that were corroded at the surface, and partially converted into indistinct wolframite crystals. In the production of this pseudomorph, lime was removed by carbonated water, and replaced by protoxides by iron and manganese.

Quartz occurs as a displacement pseudomorph after scheelite.† This may have been produced either by the direct removal of the tungstate of lime by water, or by its decomposition by carbonate of lime.

Tungstate of lead consisting of equal equivalents of tungstic acid and oxide of lead, occurs together with quartz, mica and wolframite only, at Zinnwald, in Bohemia. This association justifies the inference that the wolframite furnished the tungstic acid, which was eliminated during its decomposition by carbonated water.

K.—MOLYBDATES.

Molybdate of lead occurs in drusy cavities, and the hollows of lodes traversing limestone. Of seventeen localities, there are nine where it occurs together with carbonate of lead; a fact which seems to indicate that it has been produced by the alteration of carbonate of lead. Boussingault also mentions a specimen of molybdate of lead containing 19·5 per cent. carbonate of lead.

Molybdate of lead occurs pseudomorphous after galena.‡ The cubes of galena are covered with crusts of crystalline molybdate of lead. In some few instances there is still some galena at the centre of these pseudomorphs. Breithaupt§ states that in the lode formation XII, molybdate of lead is always seated upon galena, and also occurs pseudomorphous after it.

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* Op. cit., p. 211.
† Sillem.—Jahrb. für Mineral. etc., 1851, p. 330.
‡ Blum.—Op. cit., p. 186.
§ Die Paragenesis, p.243.
|| Websky.—Zeitschr. d. deutsch. geolog. Gesellsch. iii, 12.

Artificially prepared molybdate of lime dissolves in 505 parts of water, and it appears to dissolve more readily in water that contains a small trace of chloride of calcium, than in pure water, and as chloride of calcium is frequently present in spring water, the solution of molybdate of lime would be facilitated by it. Probably it is this soluble salt that gives rise to the production of molybdate of lead in such lodes as do not contain sulphide of molybdenum.

Molybdate of iron occurs in the neighbourhood of Nevada, in California, and consists of 40 per cent. molybdic acid, 35 peroxide of iron, 2 magnesia, 8 alkali, and 15 water.*

L.—CHROMATES.

Chromate of lead occurs in quartz veins in the granite at Beresowsk, generally upon galena and quartz, frequently also in small fissures. The exposed portions of the galena have a corroded surface, and it is covered with several other salts besides the chromate. The pyromorphite contains both chromic acid and oxide of chromium, and it is always accompanied by vanadate of lead; carbonate of lead is always situated upon the galena, or near it.†

Chromate of lead also occurs in a similar manner in the quartz veins traversing the granite of the Totschilnaja Gora, near Mursinsk, and at the Bertewaja Gora, near Nischne-Tagilsk; ‡ it also occurs in a quartz vein traversing talc-slate at Congonhas do Campo; in a talcose-mica state at Minas Geraes, in Brazil, and at Rezbanya, in Hungary.

Basic chromate of lead occurs at Beresowsk, as melanochroite, as small patches upon galena and chromate of lead, by which it is generally coated, or quite enveloped.

Chromate of lead and copper also occurs at this place as vauquelinite, either alone or with chromate or vanadate of lead, in fissures of the granite and seated upon quartz.

The description given by G. Rose shows unmistakeably the origin of the oxide of lead from decomposed galena, the sulphur of which occurs also, rarely associated with the chromate of lead. Most likely carbonate of lead is first produced, and from that not only the chromate but also the phosphate and vanadate of lead. This conjecture is supported by the fact that malachite and blue carbonate of copper are associated with chromate of lead; and since the chromium in most minerals is in the state of oxide it must be conjectured that chromic acid is produced from it. The decomposition of galena and iron pyrites at Beresowsk shows that oxidation is going on, and the presence of oxide of chromium in the pyromorphite shows that there was material for the production of chromic acid.

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* Silliman's Amer. Journ. (2) xiv, 341.

† G. Rose.—Reise nach dem Ural. i, 204.

‡ Ibid., p. 437 and 322.

Several analyses of chrome iron ore indicate the presence in it of peroxide of iron, and there can be no doubt that it has been produced by the peroxidation of some protoxide of iron, in which case the oxide of chromium may also have undergone conversion into chromate of iron at the same time. Water extracts the chromic acid from perchromate of iron, and since the water, permeating granite that is undergoing decomposition, takes up alkaline carbonates and silicates, chromate of potash would then be produced if it came in contact with the chrome iron ore undergoing such alteration. The reaction of such water with carbonated water containing carbonate of lead in solution would give rise to the production of chromate of lead.

According to this view of the case, the production of chromate of lead, melanochroite, and vauquelinite, would be dependant upon the association of chrome iron ore, with minerals that contain alkaline silicates, and galena that is undergoing conversion into carbonate of lead. The rare combination of these conditions accounts for the rare occurrence of metallic chromates.

M.—VANADATES.

Vanadate of lead occurs as dechenite at Nieder Schlettenbach, in Rhenish Bavaria. The aräoxen, containing 48·7 per cent. oxide of lead and 16·32 oxide of zinc, with vanadic and arsenic acids, occurs in this neighbourhood.

Basic vanadate of lead occurs in lodes in Mexico, quartz veins in granite at Beresowsk and at Doran, in Iceland; together with zinc and lead ores in lodes traversing grauwacke in Scotland. It is mixed with 23·33 per cent. of chloro-carbonate of lead. Damour found in this mineral 6·35 per cent. oxide of zinc and 2·96 oxide of copper, which did not seem to be combined with vanadic acid.

A mineral occurs in hollows of the compact variegated lead ore in Chili, which consists of vanadates of lead and copper, phosphate and arsenate of lead.

According to Kersten,* the cupreous slate of Mansfeld contains small quantities of vanadium.

Vanadate of copper occurs as volborthite at Syssersk and Nischne-Tagilsk, and, according to Planer, is somewhat frequent in the strata belonging to the permian series in Russia,† sometimes communicating to the sandstone a yellowish green colour, or incrusting fossil wood, etc.

Vanadates of copper and lime occur with small quantities of vanadates of magnesia, manganese, and water, as calcareous volborthite, together with psilomelan at Friedrichsrode, in the Thuringian forest. According to Credner it is a product of the decomposition of cupreous manganese, which undergoes conversion into vanadate of copper and hausmannite.

The hydrophite of Taberg, in Smaland, contains 0·115 per cent. vanadic acid. It is related to serpentine, and is mixed with a mineral containing vanadic acid and alumina.

Vanadic acid readily combines with oxide of copper and lime, as is shown by the conichalcite of Andalusia, which consists essentially of arsenate and phosphate of copper; but also contains 1·78 per cent. vanadic acid, combined with oxide of copper or lime.

Vanadium occurs in small quantities, and probably as vanadic acid, in the iron ores of Taberg, in the globular clay iron ore of Steinlade in the Harz,‡ at Tuttlingen and Wasseralfingen; in the iron ores of the Erzberg, in Styria; in the serpentine of Zöblitz, and in the compact psilomelan of Friedrichsrode.

N.—ANTIMONATES.

Antimonate of antimony will be referred to under the head of antimony ochre. It is uncertain whether other antimonates occur native. The bleiniere of Nertschinsk is stated by Hermann to be hydrated basic antimonate of lead; but Volger,§ considers it to be merely a mixture, probably of antimonate of antimony with oxide of lead.

The romeite occurring as small nests and veins in the midst of the manganese lodes at St. Marcel, in Piedmont, contains—

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* Poggend. Annal. liii, 385.

† Naumann.—Mineralogie, p. 207.

‡ Poggend. Annal. lv, 633.

§ Op. cit., p. 73.

Antimonous acid	79·31
Lime	16·67
Protoxide of manganese	2·60
„ iron	1·20

but the constitution of the mineral is undetermined.

Another mineral occurring in the mines at Jarilla, contains according to Domeyko *—

Antimonic acid	38·28
Oxide of mercury	25·14
„ copper	17·44
Water	19·14

The matrix to which this mineral is attached, consists of iron pyrites and grey copper ore, so that if the latter contained mercury it probably furnished material for the production of the above mineral.

O.—ARSENATES.

Arsenate of lime occurs hydrated as pharmacolite in fissures and hollows of lodes, accompanied by metallic arsenic, and ores of cobalt and nickel; also in old mines, where its production is still going on, probably by the action of calcareous water upon cube ore. If the production of arsenic acid were determined only by the affinity of this acid for bases, it might be expected that an arsenide constantly exposed to the influence of water containing oxygen and carbonate of lime might give rise to the production of arsenate of lime. Pharmacolite is not unfrequently coloured red by arsenate of cobalt; picropharmacolite contains 1 per cent. protoxide of cobalt, roselite consists of arsenic acid, oxide of cobalt, lime, magnesia and water, cobalt bloom occurring near Schneeberg, contains 8 per cent. of lime, and arsenic acid is not unfrequently found combined with lime and protoxide of cobalt. If, during the oxidation of arsenical cobalt ore, and its conversion into cobalt bloom, calcareous water came in contact with it, lime would be introduced into the product of alteration. That pharmacolite may have been produced in this way, is probable from the presence of protoxide of cobalt in it, and from its frequent association with arsenical cobalt ore.

Arsenous acid is produced by the decomposition of many arsenical compounds; it decomposes the carbonate of lime dissolved in carbonated water; arsenite of lime would therefore be produced by the contact of calcareous water with arsenous acid, resulting from such alteration. However, since arsenite of lime does not occur as a mineral, it is probably converted into arsenate of lime.

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* Comptes rendus, xxxv, 50.

Sillem * describes a pseudomorph of pharmacolite after realgar, consisting of an earthy mass of the mineral filling the crystals. Blum regards this as a displacement pseudomorph; but the circumstance that it occurs in limestone, admits of the conjecture that this rock has determined the higher oxidation of the arsenic to arsenic acid.

Arsenate of cobalt, containing 8 equivalents of water, occurs as cobalt bloom, in deposits of other cobalt ores.

Arsenate of nickel containing 8 equivalents of water, occurs as nickel ochre, in deposits of other nickel ores, especially with arsenical nickel ore, by the alteration of which it has chiefly been produced.

Arsenate of iron occurs as cube ore in lodes of copper ores, quartz, and brown hematite, in granular limestone with mispickel, and in drusy cavities in gneiss, together with other pyritic minerals. It consists of equal equivalents of arsenic acid, peroxide, and protoxide of iron, with 16 equivalents of water. The small cubical crystals in the beudantite, or fibrous brown hematite of Horhausen, are stated by Percy to be a mixture of sulphate of lead and cube ore. Rammelsberg, however, shows that this cannot be.

Cube ore undergoes conversion into brown hematite.

At Schöllgrippen, near Aschaffenburg, it has at many places undergone conversion into earthy brown hematite, the form being seldom retained, except where a crust of compact brown hematite has been produced. It is not improbable that calcareous water has effected the decomposition of the cube ore, arsenic acid being removed in combination with lime. In this alteration only 46 per cent. of brown hematite would be produced, hence the porous condition of the pseudomorphs. Cube ore also undergoes conversion into peroxide of iron with retention of its form.†

Skorodite occurs in beds of quartz and hornstone, quartzose, brown hematite, iron-spar, and tin ore. It consists of equal equivalents arsenic acid and peroxide of iron, with four equivalents of water. The iron sinter of Nertschinsk has the same composition. Skorodite also undergoes conversion into brown hematite.

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* Blum.—Op. cit., 2ter Nachtrag., p. 92.

† v. Leonard.—Handb. der Oryktognosie, 2nd edit., p. 166.

These pseudomorphs occur at the Raschauer Knochen, near Schwarzenberg, in Saxony, on the fissures of a ferruginous quartzose rock, mixed with copper and iron pyrites. In this alteration only 40·6 parts of hydrated peroxide of iron would be produced.

Since cube ore and Skorodite occur chiefly together with mispickel, they have probably originated from it by oxidation, the sulphuric acid produced being removed by water, in combination with lime.

The iron sinter resulting from the decomposition of mispickel and iron pyrites in old mines consists of arsenic and sulphuric acids, peroxide of iron and water.

Arsenate of zinc, with eight equivalents of water occurs in the Daniel mine, near Schneeberg. It contains some cobalt and nickel in the place of zinc.

Basic arsenate of copper, with twelve equivalents of water, occurs as rhomboidal plates at Redruth, in Cornwall.

The erinite occurring together with olivenite, at Limerick, in Ireland, contains five equivalents oxide of copper, one of arsenic acid, and two of water, with 1·77 per cent alumina.

The euchroite of Libethen, in Hungary, contains four equivalents oxide of copper and seven equivalents of water.

The copper-schaum occurring in beds and lodes consists of a basic arsenate of copper and carbonate of lime.

Octohedral arsenate of copper occurs together with olivenite. It is a hydrated arsenate and phosphate of copper.

Olivenite is also a hydrated arsenate and phosphate of copper.

Strahl-kupfer consists of arsenate of copper and arsenate of protoxide of iron.

P.—CARBONATES OF METALLIC OXIDES.

These compounds result from the decomposition of silicates by carbonic acid, and of other metallic salts by alkaline and earthy carbonates, dissolved in carbonated water. Whether they may be produced directly by the decomposition of sulphides, or whether there is not always a previous oxidation of the sulphides into sulphates, is uncertain, but the latter case is the more probable.

Carbonate of iron occurs very generally in lodes and beds.

Spathic carbonate of iron has already * been referred to. There is no mineral that seems better adapted than this for tracing decomposition by means of chemical analysis. Its composition is well known. The slightest alteration, by oxidation, is rendered evident by deficiency of carbonic acid, and presence of water. But the exact direct estimation of carbonic acid is very difficult. By ignition of carbonate of iron, the result obtained is inaccurate, because of the peroxidation of the iron, and because, when hydrated peroxide is present, water is driven off together with carbonic acid. The estimation by treating the carbonate with an acid is inaccurate, because the perfect separation of carbonic acid requires the application of heat.

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* English edition, i, 51.

As regards testing any given iron-spar for chemically combined water, errors may arise from the presence of organic substance from which water would be formed on the application of heat. Moreover, magnetic oxide of iron is sometimes produced by the alteration of iron-spar. Fortunately, this may be detected by the magnet. These remarks will suffice to show the difficulty attending analyses of altered iron-spar, or sphærosiderite. Hence former analyses, in which these points were disregarded, do not afford data that are of much service for judging as to the nature of the product.

The following analyses show an almost constant presence of manganese, sometimes in considerable amount. The pure carbonate of iron and manganese is white; white iron-spar also occurs; but more frequently it is yellow, green, or reddish-brown, and ash-grey. These colours are due to oxidation; but they do not indicate whether the iron or manganese, or both, are in the state of peroxide. The peroxidation of manganese in iron-spar is easily recognizable by evolution of chlorine on treating it with hydrochloric acid.

The following specimens of dark-coloured iron-spar gave the following results:—

1. From Lobenstein. Iron-black lustre. Streak rather yellow; powder, brown or yellowish. No evolution of chlorine.

2. From Lobenstein. Very magnetic; iron-black lustre. Streak and powder, brown. No evolution of chlorine.

3. From Lobenstein. Iron-black lustre only at some parts; generally without lustre. Streak, reddish brown; powder, brown. Strong smell of chlorine; litmus paper bleached instantly.

4. From Schmalkalden. Almost without lustre. When scraped, the crystal faces presented iron-black lustre. Strong smell of chlorine, etc., as before.

The white streak of 1 showed that the oxidation had not extended beyond the surface; and as no chlorine was given off, it could not have affected the manganese. The magnetic polarity of 2 showed that oxidation had taken place. As no chlorine was given off, the manganese could not have been affected. In 3 and 4, iron and manganese were both peroxidized.

The external characters, colour, lustre, etc., of the above specimens, were nearly the same in all, and still the oxidized products were very different. It follows, from these observations, that in the decomposition of iron-spar, the iron is always peroxidized, the manganese only sometimes. Magnetic oxide of iron does not seem to be often produced; for, in testing a number of specimens of decomposed iron-spar, only one was found to be magnetic.

The production of magnetic oxide of iron would require the separation of carbonic acid from some of the carbonate of iron; but no process is known by which this change can be supposed to take place. If peroxide of iron could displace the carbonic acid, magnetic oxide of iron would be of very frequent occurrence, since peroxide of iron is always produced in the alteration of iron-spar. Magnetic oxide of iron is anhydrous; the peroxidation of iron-spar is always attended with hydration. The conversion of iron-spar into magnetic oxide of iron would, therefore, involve oxidation without hydration.

Instances of the conversion of iron-spar into magnetic oxide of iron have already been given;* but, among the fifty-seven analyses of iron-spar that follow, there is only one (No. X) which is said to be magnetic. Iron-spar rarely occurs in deposits of magnetic iron ore; it is met with only in a few places in Sweden, Norway, and Silesia. Therefore, the conversion of iron-spar into magnetic oxide of iron, is rare, and requires peculiar unfrequent conditions. Hence, at Lobenstein, iron-spar occurs that is sometimes magnetic and sometimes not, and, as it would seem, the latter is the more frequent case.

In most analyses of iron-spar, the quantities of bases and carbonic acid are given; and in calculating the amounts of carbonates, these quantities sometimes agreed well; in other instances, the quantity of carbonic acid found was much less than that indicated by calculation. This was the case, even with analyses of iron-spar that had undergone alteration, and consequent loss of carbonic acid, so that there was probably some inaccuracy in the estimations. In those few instances where the calculated amount of carbonic acid was greater than that found, the quantity of hydrated peroxide of iron was calculated from the difference between the two values. There is not a single analysis of altered iron-spar or sphærosiderite, in which any attempt was made to ascertain the condition of the iron and manganese.

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* English edition, ii, 518.

	I.	II.	III.	IV.
Carbonate of iron	88·98	83·03	87·77	79·57
„ manganese ..	4·86	6·07	1·21	15·41
„ lime	2·23	0·89	..	..
„ magnesia ..	..	1·57	0·52	1·97
Peroxide of iron	..	4·10	10·28	..
	96·07	95·66	99·78	

Analysed by

I. Iron-spar, from Dankerode (Lower Hartz) Klaproth.*

Dirty yellow, with a few brown spots; gave no water by ignition.

II. Iron-spar, from Kemlas (Baireuth) Klaproth.

Dark reddish brown; undoubtedly contained hydrated peroxide of iron.

III. Sphærosiderite, from Steinheim, near Hanau } Klaproth.

Yellowish and blackish brown; but did not contain any water. The quantities of peroxide calculated for II and III, of course, cannot be perfectly correct.

IV. Iron-spar from Siegen Schnabel.

	V.	VI.	VII.	VIII.	IX.
Carbonate of iron	96·03	69·5	73·5	71·0	81·0
„ manganese ..	3·06	..	1·0	18·3	13·0
„ lime	0·36	..	..	..	3·5
„ magnesia	0·31	31·6	25·2	5·0	1·5
Peroxide of iron	..	..	..	..	..
Gangue	..	..	..	5·7	1·0
	99·76	101·1	99·7	100·00	100·0

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* Beiträge zur chemischen Kenntniss der Min. iv, 107, vi, 315.

Analysed by

V. Sphærosiderite, previously mentioned. Stromeyer.

It contained only a trace of water.

VI. Pale yellow iron-spar, from Allevard (Dep. Isère).

Did not contain any manganese.

VII. Pale yellow iron-spar, from Autun (Dep. Saone et Loire).

VIII. Pale yellow iron-spar, from Allevard.

IX. Pale yellow iron-spar, from St. George de Huntières (Savoy).

	X.	XI.	XII.	XIII.	XIV.
Carbonate of iron	55·0	70·0	82·7	85·35	85·35
„ manganese ..	5·7	9·4	7·0	0·97	1·29
„ lime	19·2	8·8	..	..	1·78
„ magnesia	2·6	4·2	1·6	11·34	9·45
Gangue	17·0	9·1	8·7	..	2·00
	99·5	101·5	100·0	97·66	99·87

X. Reddish yellow iron-ore, imbedded in limestone, from La Voutte (Dep. Ardèche).

XI. Yellow and grey iron-ore, imbedded in carboniferous limestone, at Martignes (Dep. Rhone).

XII. Iron-ore, reddish outside, inside grey and arenaceous, from Chailland (Dep. Majenne).

It contains about 2·5 per cent. peroxide of iron, which is undoubtedly in the state of magnetic oxide, as this ore is strongly affected by the magnet. It also contains bituminous substance.

XIII. Iron-spar, from Escourlegny, near Baigorry.
XIV. Iron-spar, from Pacho, near St. Fé de Bogota
} Analysed by Berthier.*

	XV.	XVI.	XVII.	XVIII.
Carbonate of iron	84·7	85·83	70·09	74·56
„ manganese ..	2·75	10·52	1·62	14·73
„ lime	1·78	..	..	..
„ magnesia	7·56	1·47	26·87	9·45
Gangue	2·2	..	..	1·40
	98·99	97·82	98·58	100·14

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* Annal. des Mines, viii, 887, and (2) iii, 25.

	Analysed by
XV. Iron-spar, from Pierre-Rousse (Dep. Isère) XVI. Iron-spar, from Rancié, near Vicdessos (Pyrenees) XVII. Iron-spar, from Grande-Fosse (Dep. Isère) XVIII. Iron-spar, from Bendorf, near Coblenz	Berthier.*

	XIX.	XX.	XXI.	XXII.	XXIII.	XXIV.
Carbonate of iron ..	72·31	72·18	96·72	78·41	15·59	59·99
„ manganese	16·67	4·86	..	16·25	1·19	40·66
„ lime ..	1·78	1·78	3·28	1·19	..	..
„ magnesia	3·36	..	..	3·77	82·91	..
Peroxide of iron ..	..	22·23	..	..	..	..
Water	..	..	..	0·25	..	..
Gangue	4·20	..	..	..	..	..
	98·32	101·05	100·00	99·87	99·69	100·65

	Analysed by
XIX. Iron-spar, from Stahlberg, near Siegen	Berthier.*

In VI, IX, XIII, XIV, XVI, XVII, XIX, the carbonic acid found was from 0·13 to 2·42 per cent. more than that calculated from the amount of bases; so that these analyses are inaccurate. In VII, VIII, XV, XVIII, it was from 0·44 to 4·49 per cent. less than the calculated amount. It may therefore be inferred that these specimens contained hydrated oxide of iron.

XX. Iron-spar, from Reddarhyttan (Westmanland)	Hisinger.†
XXI. Compact sphærosiderite.‡ A deposit from water	Bischof.
XXII. Pale yellow transparent iron-spar crystals, from Silbernen Nagel, near Stolberg	Stromeyer.§

The water did not seem to be combined; but it is remarkable that the carbonic acid is 1·89 per cent. more than equivalent to the bases.

XXIII. A mineral, from Pfitschthal (Tyrol)	Magnus.‖

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* Annal. des Mines, viii, 887, and (2) iii, 25.

† Afhandl. i, Fysik, ii, 158.

‡ English edition, i, 157.

§ Loc. cit. p. 270.

‖ Pogg. Ann. iv, 145.

From the small amount of carbonate of iron, this can hardly be called iron-spar.

Analysed by

XXIV. Iron-spar, from Ehrenfriedersdorf Magnus.

	XXV.	XXVI.	XXVII.	XXVIII.
Carbonate of iron	81·181	80·891	93·259	81·68
„ manganese ..	12·154	4·111	2·444	12·36
„ lime	..	1·479	1·051	0·71
„ magnesia.. ..	4·933	3·359	Spur	3·11
Gangue	0·23	9·73	0·60	0·48
	98·498	99·570	97·354	98·34

XXV. White iron-spar, from Hackenburg (Nassau).

XXVI. White iron-spar, from Steinmark.

XXVII. Black iron-spar, from Babkowsky (Upper Silesia). Contains 1·92 per cent. carbon.

XXVIII. Bright yellow iron-spar, from Siegen.

	XXIX.	XXX.	XXXI.	XXXII.
Carbonate of iron	76·01	77·23	73·84	79·34
„ manganese ..	13·50	15·37	12·95	8·69
„ lime	1·12	..	0·82	5·43
„ magnesia	7.87	6·55	4·20	7·60
Peroxide of iron	..	..	7·27	..
Gangue	0·95	..	0·65	..
	99·45	99·15	99·74	101·06

XXIX. Yellow iron-spar, from Siegen.

XXX. White iron-spar, from Stahlberge, near Müsen.

XXXI. Brown red iron-spar, from Siegen.

XXV—XXXI analysed by Karsten.* In XXV, XXVIII, XXIX, XXX, XXXI, the carbonic acid found amounts to from 0·27 less to 1·275 per cent. more than that calculated from the bases. In the case of XXVIII, the colour might indicate hydrated peroxide of iron, but here there is the remarkable excess of 1·275 per cent. Therefore these analyses are inaccurate. In XXVI and XXVII the amounts of carbonic acid found correspond with those calculated so closely that the estimation may be regarded as correct.

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* Rammelsberg's Handwörterbuch. Supplement 1, p. 139.

	Analysed by
XXXII. Crystallized iron-spar, from Neudorf, near Harzgerode	Pieschel.[*]

	XXXIII.	XXXIV.	XXXV.	XXXVI.
Carbonate of iron	70·58	70·20	85·45	70·70
„ manganese ..	11·83	28·92	6·80	20·57
„ lime	..	0·14	2·00	0·66
„ maguesia	5·12	0·50	4·74	3·76
Peroxide of iron	12·44	..	..	5·26
	99·97	99·76	98·99	100·95

	Analysed by
XXXIII. Brownish-black crystallized iron-spar, from Carinthia, partially converted into brown iron-ore	Rosengarten.[†]
XXXIV. Sphærosiderite, from the basalt of the Alte Birke mine, near Siegen	Schnabel.[‡]
XXXV. White crystallized iron-spar, from Bieber (Hessen)	Glasson.[§]
XXXVI. Yellow crystallized iron-spar, from Harzgerode	Herter.

	XXXVII.	XXXVIII.	XXXIX.	XL.
Carbonate of iron	64·04	81·99	78·57	73·87
„ manganese ..	16·56	14·63	15·63	17·17
„ lime	20·22	0·71	0·64	0·89
„ magnesia	..	1·68	2·62	6·78
Peroxide of iron	..	..	..	1·43
Silica and loss	1·10	1·01	2·51	..
	101·92	100·02	99·97	100·14

	Analysed by
XXXVII. Green crystallized iron-spar, from Altenberg, near Aix-la-Chapelle	Monheim.[‖]

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[*] Rammelsberg's Handwörterbuch. Supplement 1, p. 139.

[†] Ibid., Supplement 3, page 112.

[‡] Ibid.

[§] Annal. der Chemie. u. Pharmacie. 62, 89.

[‖] Verhandlungen der naturhist. Vereins der Rheinlande—Jahrgang, etc., p. 39.

	XLI.	XLII.	XLIII.	XLIV.
Carbonate of iron	78·77	78·64	77·41	78·68
„ manganese ..	14·02	17·48	16·83	13·25
„ lime	0·57	0·73	0·64	0·57
magnesia	4·07	2·96	4·64	4·91
Silica and loss	2·54	0·17	0·33	2·55
	99·97	99·98	99·85	99·96

	XLV.	XLVI.	XLVII.	XLVIII.
Carbonate of iron	75·64	81·42	75·85	81·12
„ manganese ..	12·24	15·65	12·38	13·43
„ lime	0·82	0·29	0·61	0·45
„ magnesia	4·66	2·44	5·14	4·51
Silica and loss	5·74	0·08	4·60	0·45
	99·10	99·88	98·58	99·96

	XLIX.	L.	LI.
Carbonate of iron	75·17	31·19	..
„ manganese ..	15·97	8·48	16.56
lime	0·62	1·68	0·60
magnesia	8·21	9·45	0·44
Peroxide of iron	..	38·83	76·76
Silicate and loss	..	3·24	..
Water	..	5·71	5·64
	99·97	98·58	100·00

The specimens of iron-spar, XXXVIII to XLIX, are from the neighbourhood of Siegen, and were analysed by Schnabel.[*]

In these analyses, the carbonic acid found corresponds with the amounts calculated from the bases, except in the case of XL, either completely, or within from 0·01 to 0·09 per cent.

Since such a correspondence cannot be expected to result from direct estimation, it is probable that these amounts were calculated from the bases.

Therefore these analyses do not admit of any conclusion as to whether peroxidation had taken place or not, although it cannot be supposed that the twelve specimens of iron-spar were all quite unaltered.

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[*] Rammelsberg's Handwörterbuch. Supplement 4, p. 209.

In XL the calculated amount of carbonic acid is 0·79 per cent. more than that found. From this difference the amount of peroxide of iron was calculated.

L. Brownish-red iron-spar, from near Siegen. Schnabel.

The oxidation of this ore was very far advanced.

Whether Schnabel's opinion that the manganese was not peroxidized, was based upon its behaviour with hydrochloric acid or not is not stated.

LI. Black iron-spar from the alteration of XLII.

In the former the iron amounts to 4·659 times as much, and in the latter to 4·539 times as much as the manganese.

These proportions are so nearly alike, that it may be inferred that both oxides are peroxidized without either carbonate being removed to any extent.

	LII.	LIII.	LIV.	LV.	
Carbonate of iron ..	77·72	47·24	69·99	35·30	
„ manganese	0·21	..	0·78	..	
„ lime ..	1·02	..	0·14	0·41	
„ magnesia	2·51	4·40	3·67	1·57	
Sulphate of lime ..	0·05	..	..	0·64	
„ magnesia ..	..	..	0·13	..	
Peroxide of iron ..	1·30	7·46	7·77	5·93	
Alumina	0·77	..	0·52	8·67	as silicates.
Lime	..	..	..	0·68	
Magnesia	..	..	..	0·35	
Peroxide of iron ..	..	..	..	1·16	
Silica	0·93	0·81	1·92	20·23	
Carbon	14·61	35·34	11·76	20·07	
Water	0·92	4·14	3·01	5·09	
	100·04	99·39	99·69	100·10	

LII bis LV. Black-band, from mines near Bochum, in Westphalia } Analysed by Schnabel.*

These ores form a layer, two feet thick, between carboniferous sandstone and shale.

The large amounts of carbon and the presence of peroxide of iron and water render it difficult to account for the origin of these minerals.

It is not probable that carbonate of iron would be peroxidized in the presence of carbon. More likely hydrated peroxide of iron was partially reduced by the carbon, the carbonic acid combining with the protoxide. This would account for the fact that there is no manganese in LIV and LVI, and but very little in LIII and LV. Hence this black-band has a composition quite different from that of iron-spar.

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* Poggendorff's Annalen, lxxx, p. 441.

In a drusy cavity in the melaphyr at Oberstein, I found a thin crust of hydrated peroxide of iron upon a very thin layer of quartz; above it yellowish-brown sphærosiderite, and then white calc-spar, containing only traces of iron and magnesia. The sphærosiderite consisted of—

Carbonate of iron	56·06	100·00
,, manganese	14·79	
,, lime	14·01	
,, magnesia	15·14	

In this product of infiltration, therefore, we find a considerable amount of manganese. The analyses of iron-spar and sphærosiderite generally show a considerable amount of carbonate of manganese, so that it seems to be a rule that this carbonate was deposited, together with carbonate of iron, in the formation of iron-spar and sphærosiderite. Among the above analyses, VI is the only one where there seems to have been no manganese. This admits of the inference that the water from which it was deposited did not contain manganese. The analyses of spring water show that such a case is unfrequent. It is worthy of notice that the rocks which furnish material for the production of iron and manganese ores, generally contain both metals as silicates, and that they are associated as carbonates both in the water permeating the rocks and in the deposits from this water. No other metals can be traced so distinctly in their passage from rocks to deposits of ore as iron and manganese; but it is very questionable whether there is any reason to suppose that other metals have been accumulated by means at all different.

Among the carbonates which are shown by the above analyses to accompany the carbonates of iron and manganese, carbonate of magnesia is more frequently and generally more abundant than carbonate of lime. Of sixteen specimens of magnesite, there are twelve in which there is no lime, but carbonate of iron from 1·26 to 54·62 per cent. Among these twelve there are seven which contain from 0·09 to 3·19 per cent. carbonate of manganese.* Consequently, both iron-spar and magnesite show that carbonate of iron combines more readily with carbonate of magnesia than with carbonate of lime. It cannot be assumed that the water from which these minerals was deposited contained no lime, for out of the analyses of spring water there is, perhaps, not one in which the presence of carbonates of iron and magnesia alone is indicated; but, on the contrary, these analyses show that carbonate of lime generally preponderates.

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* Schrötter and Berthier analysed several varieties, in which the carbonate of lime amounted to twice as much as the carbonate of magnesia. But these minerals cannot be called magnesite; they properly belong to varieties of bitter-spar or dolomite.

As regards the separation of carbonates of iron and magnesia, especially from water containing these carbonates together with carbonate of lime, it is evident that crystallization is a partial cause, if not the only one; for those varieties of magnesite that are ferruginous are also the most crystalline, while those that are free from iron are compact. Thus the compact magnesite of Frankenstein often contains only ·009 to ·048 per cent. oxide of iron, alumina, silica, and traces of phosphoric acid.

It is known that isomorphous substances crystallize together in variable proportions. The form of the carbonates of iron, manganese, lime, and magnesia, is the rhombohedron. It might, therefore, be expected that these carbonates, that are generally present in the water of every spring, would crystallize together, according to their proportion in the water. Crystallized quadruple carbonates do occur, but the relative proportion of the individual carbonates differs entirely from that in the water of springs. Iron-spar, in which carbonates of iron and manganese preponderate, as well as magnesite, in which these carbonates occur in large amount, could not have been produced from water in which carbonates of iron and manganese occur in such very small proportion to carbonates of lime and magnesia.

The angles of the rhombohedrons in which the above carbonates crystallize are not the same. It is a question whether those of them whose crystalline forms are most alike crystallize together. The obtuse angle of the

A Magnesite Rhombohedron is	107°	25′
B Iron spar	107°	....
C Manganese spar	106°	51′
D Calc-spar	105°	5′

The difference between

B and C is		9′
A „ B „		25′
A „ C „		34′
C „ D „	1°	46′
B „ D „	1°	55′
A „ D „	2°	20′

These differences generally indicate that this is the case. Between the angles of iron-spar and manganese-spar, the difference is least, and this agrees with the general association of these carbonates in iron-spar and sphærosiderite. The next smallest difference between magnesite and iron-spar corresponds with the frequent association of carbonates of iron and magnesia in iron-spar, sphærosiderite, and magnesite. The somewhat larger difference between magnesite and manganese-spar corresponds to the frequent association of carbonates of magnesia and manganese in iron-spar sphærosiderite, and not unfrequently in magnesite. The greatest difference is between magnesite and calc-spar. Nevertheless, the combination of carbonate of lime with carbonate of magnesia in bitter-spar and dolomite is the most frequent of any. But it has been shown* that by evaporation of solutions containing bicarbonates of lime and magnesia, both carbonates are never separated simultaneously; and, therefore, the indirect production of dolomite is more probable. It is, moreover, a general chemical fact, that a great number of compounds can be produced only indirectly.

Among the carbonates in question, there is none that occurs so frequently, almost pure, as carbonate of lime. The angle of calc-spar rhombohedrons can, therefore, be determined with the greatest accuracy. However, the observations of Breithaupt,† and other mineralogists, show deviations, which, according to Breithaupt, are due to admixtures of other bases.

However, since the obtuse angle of the calc-spar rhombohedron is increased 1° 10′ when equal equivalents of carbonates of lime and magnesia are combined, it might be expected that even the most minute quantities of the latter carbonate would increase the angle of calc-spar, unless it were supposed that these carbonates are chemically combined only in bitter-spar, where they are in simple equivalents.

If the obtuse angle of calc-spar increased in proportion to the amount of carbonate of magnesia, 1 per cent. of this substance should increase the angle 1·4′, and such a difference would be easily recognizable by the aid of a good goniometer.

I am acquainted only with one instance in which the pure crystallized magnesite has been analysed and measured. This mineral occurs near Lofthuus and Snarum (Norway). It contains 0·786 per cent. protoxide of iron; and Breithaupt found the angle the same as in other varieties, = 107° 28·5′, or nearly as great as it is stated to be in mineralogical works. Since all measurements, with the above exception, were certainly made with more or less impure magnesite, it would seem that admixture of other carbonates does not increase the angle of the rhombohedron. Breithaupt[*] found this angle, 107° 14′, in the mineral called by him mesitin, and containing

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* See ante, p. 169.

† Schweigger's Journ. liv. 253.

Carbonate of iron	....	54·62
„ magnesia	....	44·33

Whether this mineral is regarded as iron-spar or magnesite, it is, at least, certain that the value of this angle falls between those of magnesite and iron-spar, and, therefore, differences may be expected to exist in magnesite, corresponding to smaller amounts of carbonate of iron.

It has already been remarked, that magnesite rarely contains carbonate of lime. The measurement of the obtuse angle of calcareous magnesite would be very interesting; for it might be expected that the angle would be lessened by small amounts of carbonate of lime, just as small amounts of carbonate of magnesia increase the angle of calc-spar.

If, according to Breithaupt's[†] opinion, a small percentage of manganese increases the angle of iron-spar, the angle of the pure manganese-spar rhombohedron should be greater than that of pure iron-spar. But the data given in mineralogical works are opposed to this, and show that the reverse is the case. Further examination of this subject would be very desirable.

Carbonate of manganese occurs as manganese-spar in lodes, together with zinc blende, iron pyrites, quartz, etc.

	I.	II.	III.	IV.
Carbonate of manganese	82·2	73·70	89·91	86·64
„ iron	7·3	5·76	..	..
„ lime	8·9	13·08	6·05	10·58
„ magnesia	1·6	7·26	3·30	2·43
Water	..	0·05	0·44	0·31
	100·0	99·85	99·70	99·96

	Analysed by
I. Manganese spar of Freiberg	Berthier.[‡]
II. The same mineral.	
III. Manganese-spar of Kapnik, in Hungary	Stromeyer.[§]

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[*] Poggend. Annal. lxx, 147.

[†] Loc. cit. p. 286.

[‡] Annales des Mines, vi, 593.

[§] Göttinger gelehrte Anzeigen, 1833, p. 1081.

Analysed by

IV. Manganese-spar of Nagyag, Transylvania } Stromeyer.*

	V.	VI.	VII.	VIII.	IX.
Carbonate of manganese	81·42	74·55	79·94	97·1	67·48
" iron	3·10	15·01	11·04	0·7	3·22
" lime	10·31	Spar	2·43	1·0	18·81
" magnesia ..	4·28	..	..	0·8	9·97
Organic substance and loss ..	..	10·11	6·22	..	..
Sesquioxide of manganese ..	..	..	..	0·1	..
Water	0·38	..	..	..	..
Clay and sand	..	0·33	0·37	..	..
	99·44	100·00	100·00	99·7	99·48

Analysed by

V. Pink manganese-spar of Voigtsberg, in Saxony } Kersten.†

VI. and VII. Earthy carbonate of manganese of Glandree, County Clare, Ireland } Kane.‡

VIII. Dark pink manganese-spar of Vieille, in the Pyrenees } Gruner.§

IX. Pink, radiated manganese-spar of Schemnitz } Rammelsberg.||

According to Breithaupt this mineral is a species of arragonite, and therefore bears the same relation to manganese-spar, that arragonite does to calc-spar.

The above analyses do not indicate any essential alteration of manganese-spar by peroxidation, though the artificially prepared carbonate is extremely susceptible of alteration in this way. Manganese-spar, however, becomes brown when exposed to the air, and the pink colour may be due to incipient peroxidation of both manganese and iron conjointly.

The production of manganese-spar appears therefore to have taken place under exclusion of atmospheric air, or under such other circumstances as prevented peroxidation, for instance, the presence of organic substances, the existence of which appears to be indicated by the analyses Nos. VI and VII.

Other phenomena show, however, that in some cases the

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[*] Göttinger gelehrte Anzeigen, 1833, p. 1081.

[†] Journ. für prakt. Chemie, xxxvii, 163.

[‡] Phil. Mag., 1848, p. 37.

[§] Ann. des Mines (3) xviii, 61.

[||] Poggend. Annal. lxviii, 511.

natural tendency to peroxidation has its full course. The deposits of peroxide of manganese from the water of springs have already been referred to.* Fresenius † showed, by the analysis of a sinter deposited from the water issuing at 158° F from the Kochbrunnen, at Wiesbaden, that carbonate of iron undergoes oxidation before carbonate of manganese; and this agrees with the known fact that the former is much more susceptible of oxidation than the latter.

There can be no doubt that the sesquioxide of manganese that occurs in manganese ores, originates from carbonate of manganese; for this is the only compound of manganese that occurs in the water of springs. The mineral already referred to as occurring at Cummington,‡ shows, that by the decomposition of hornblende rich in manganese, carbonates may be produced such as are met with in manganese-spar.§

On the other hand, there is little probability that the peroxides of manganese have originated from manganese-spar; and it is far more likely that they have been produced directly during the deposition of carbonate of manganese from the water of springs. This opinion is supported by the fact that there is not any pseudomorph manganese ore after manganese-spar.

If manganese-spar has been produced by displacement of carbonate of lime,|| it is evident that in this case also the above-mentioned conditions of the production of manganese-spar must have prevailed.

Moreover, since pyrolusite, hausmannite, and manganite occurs pseudomorphous after calc-spar, it is very probable that no small part of the manganese ores have been produced by displacement of carbonate of lime by carbonate of manganese dissolved in carbonated water. The frequent association of calc-spar and the manganese ores, is also evidence in favour of this view.

Carbonate of zinc occurs as calamine, in transition limestone and in lodes, frequently associated with silicate of zinc and bitter-spar, as at Altenberg, near Aix-la-Chapelle. It sometimes contains carbonates of lead, iron, manganese, lime, and magnesia. Carbonate of zinc may originate from the silicate zinc.

It is equally probable that carbonate of zinc may be produced by the decomposition of zinc blende, and from sulphate of zinc.

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* English edition, i, 160.

† Jahrbuch des Vereins für Naturkunde in Herz. Nassau., vi, 160.

‡ English edition, ii, 355.

§ Dana.—Amer. Journ. (2) ix, 410.

|| English edition, ii, 57.

Carbonate of zine occurs as displacement pseudomorphs after calc-spar; quartz and pyrolusite occur as displacement pseudomorphs after calamine.

Hydrocarbonate of zinc occurs but rarely together with calamine.*

The aurichalcite occurring in some copper mines in he Altai, consists of hydrated carbonate of zinc, and carbonate of copper in varying proportions. Sometimes it contains from 2·2 to 8·6 per per cent. of lime.

Carbonate of copper occurs combined with an equivalent of hydrated oxide of copper, as malachite, together with other copper ores in lodes and beds. At some places near Lake Superior, it occurs as a product of the oxidation of metallic copper, as well as in cavities of the amygdaloid rocks.

Blue carbonate of copper consists of two equivalents carbonate of copper and one of hydrated oxide. It occurs less frequently than malachite in the same localities.

Malachite appears to have originated chiefly by the reaction of bicarbonate of lime with sulphate of copper, resulting from the oxidation of sulphide of copper.

It occurs in a fibrous condition with the form of blue carbonate, at Chessy, near Lyons, and the various stages of the alteration may be traced.†

The precipitate produced by mixing solutions of equal equivalents of sulphate of copper and carbonate of soda, in 60 parts of water, is blue, and after some 30 hours becomes more dense, and of a green colour.‡ ts composition No. I corresponds with that of malachite No. II, and also with that of blue carbonate No. III.

	I.		II.		III.
Oxide of copper	70·90	2	71·87	3	69·09
Carbonic acid	19·46	1	19·96	2	25·69
Water	9·64	1	8·17	1	5·22
	100·00		100·00		100·00

Carbonate of copper dissolves in 9388 parts of carbonated water, so that the production of malachite may be supposed to take place by deposition from water, and the characters of malachite are indicative of such a mode of production.

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* See ante, p. 444.

† Blum.—Op. cit., p. 215.—G. Rose.—Reise nach dem Ural, i, 409.

‡ Poggendorf Annalen., lxxxiv, 466.—Senarmont.—Ann. de chim. et de phys., (3), xxxii, 129.

The blue colour of the precipitate produced by carbonate and bicarbonate of soda, from solutions of copper salts, is regarded by H. Rose as not being due to a compound corresponding to the native blue carbonate of copper, but to a compound of carbonate of copper and carbonate of soda, that is decomposed by washing, with alteration of the colour to green.

It does not, therefore, appear how the native blue carbonate has been produced, but the production of pseudomorphous malachite after blue carbonate of copper, would be analogous to the conversion of the blue precipitate into green carbonate.

Malachite sometimes occurs pseudomorphous after copper pyrites,* the pseudomorphs being filled with earthy brown hematite, or earthy tile ore, and since malachite is so frequently accompanied by iron ochre, as in Siberia, it is very probable that it has in many instances originated from compact masses of copper pyrites.

In the oxidation of copper pyrites it would yield 43·18 per cent. oxide of copper, and 43·52 peroxide of iron. The former corresponds to 60·08 parts of malachite, the latter to 51·03 parts hydrated peroxide of iron, so that there would be an increase of weight in this alteration to the extent of 11·11 per cent., and since the density of malachite and brown hematite is rather less than that of copper pyrites, there would be an increase of bulk rather more than 11·11 per cent.

Malachite is produced also by the decomposition of grey copper ore. Very fine pseudomorphs of this kind occur in the dolomite of the magnesian limestone series at Bieber.†

The largest amount of copper in grey copper ore is 42·5 per cent., corresponding to 74·08 parts malachite. If the other constituents of the grey copper ore were entirely removed there would be a reduction of weight to the extent of 24·92 per cent., corresponding to a contraction in volume of about 5 five per cent. This would account for the compact character of the pseudomorphous malachite.

Malachite also occurs as displacement pseudomorphs after calcspar, carbonate of lead,‡ and calamine.§

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* Blum.—Op. cit., p. 218 ; Nachtrag, p. 117.

† Blum.—Op. cit. Nachtrag, p. 118.

‡ Ibid. p. 309.

§ Ibid., 2$^{\text{ter}}$ Nachtrag, p. 139.

Blue carbonate of copper occurs as a product of the alteration of grey copper ore, and as a displacement pseudomorph after carbonate of lead and bitter-spar.

The mysorin occurring in Hindostan appears to be an anhydrous malachite.

Calcareous malachite, aurichalcite, and the buratite of Loktefskoi, in the Ural, and of Chessy, contain carbonate of copper.

Carbonate of lead dissolves in 50816 parts of carbonated water. It occurs very frequently in lodes, sometimes also in beds in sedimentary limestone, almost always associated with galena, from which it has in most instances originated.

Carbonate of lead also occurs pseudomorphous after sulphate of lead, leadhillite, chloro-carbonate of lead, and linarite. Quartz, brown hematite, malachite, and silicate of copper occur pseudomorphous after carbonate of lead. Carbonate of lead occurs combined with 7·02 per cent. carbonate of zinc, at Monte Poni, in Sardinia, and another variety of the same mineral occurring near Aix-la-Chapelle, contains only 0·19 carbonate of lead, so that these substances appear to replace each other.

A specimen of carbonate of lime from Wanlockhead contained 7·8 per cent. carbonate of crystallized lead, the plumbocalcite of Leadhills 2·34 per cent., and a compact arragonite at Tarnowitz 3·9 per cent.

Carbonate of bismuth occurs mixed with basic sulphate of bismuth as pseudomorphs after sulphide of bismuth at Ullersreuth, Aue, and Johanngeorgenstadt; also after metallic bismuth at Schneeberg.*

The bismuth-spar of the gold mines at Chesterfield, South Carolina consists of hydrated basic carbonate of bismuth, with small quantities of earthy admixtures.

Carbonate of nickel occurs, combined with hydrated oxide of nickel and water, as a coating upon the chrome iron ore, at Texas, in Pennsylvania.

The herrerite associated with lead and silver ores at Albaradon, in Mexico, is said to consist of oxide of nickel, carbonic acid, and tellurium.

Artificially prepared carbonate of nickel dissolves in 2470 parts of water.

Carbonate of cobalt does not occur native. It is even more soluble than carbonate of nickel.

Carbonates of cerium, lanthanium, etc., occurs in the parisite of the emerald mines of the Musso valley in New Grenada.

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* Breithaupt.—Poggend. Annal., liii, 627.

The hydrocerite occurring in the beds of copper pyrites in gneiss, with cerite and allanite, etc., is a carbonate of lanthanium.

Carbonate of uranium is said to occur native.

The liebigite associated with the pitchblende of Adrianople is hydrated carbonate of uranium and lime.

Carbonate of silver occurs at Real-de-Catorce, in Mexico, and in calc-spar veins at Wolfach, in Baden.*

Artificially prepared carbonate of silver dissolves in from 22,812 to 20,524 parts of water, and in 2,084 parts of carbonated water.

Q.—PHOSPHATES.

The production of phosphates has already been referred to.† A solution of phosphate of lime in carbonated water, decomposes solutions of metallic sulphates and bicarbonates.

Phosphate of iron.—The protophosphate occurs in copper mines, together with iron pyrites, magnetic pyrites, etc., in tin lodes, brown hematite, basaltic rocks, and often in the cavities of fossil remains.‡

Anglarite, ficinite, and delvauxite, are amorphous varieties of phosphate of iron.

Phosphate of peroxide of iron occurs hydrated as green iron ore. It probably originates from the protophosphate by peroxidation, and it sometimes contains protoxide of iron.

Carphosiderite, kakoxen, and beraunite are analogous minerals.

Diadochite is a compound of hydrated perphosphate and persulphate of iron. Kakoxen also contains sulphuric acid.

Phosphate of manganese occurs combined with phosphate of iron as triplite, triphylin, pseudotriplite, huraulite, alluandite, and iron apatite, in granite. These minerals vary much in composition, in consequence of their susceptibility to peroxidation. The following analyses indicate interesting alterations.

	I.	I A.	II.
Phosphoric acid	41 97	36·39	39·40 — 3·01
Peroxide of iron	..	49·10	51·22 — 2·12
Protoxide of iron	49·15	..	.. ..
„ manganese	4·75	..	.. ..
Sesquioxide	..	9·11	4·96 + 4·15
Silica	3·44	..	.. ..
Water	0·69	5·40	4·42 + 0·98
	100·00	100·00	100·00

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* Naumann.—Mineralogie, 1852, p. 228

† English edition, ii, 34.

‡ Ibid. ii, 34.

	Analysed by
I. Unaltered triphylin of Bodenmais	Fuchs.
I, A. Weathered „ „	

II. Shows the proportion of the constituents when the iron and manganese are assumed to be in the state of sesquioxides. The alteration would therefore consist in the replacement of the lithia, and 2·12 peroxide of iron by 4·15 sesquioxide of manganese, those bases being removed in combination with 3·01 parts of phosphoric acid. The water is probably combined with peroxide of iron.

The variation in the composition of the triphylin of Bodenmais is shown by the following analyses, Nos. III and IV.

	III.[*]	IV.[†]	V.
Phosphoric acid	36·36	40·70	43·00
Peroxide of iron	..	39·97	26·67
Protoxide of iron	44·52	..	..
„ manganese	5·76	..	..
Sesquioxide of manganese	..	9·80	24·00
Silica	5·09	7·28	2·23
Soda	5·16	1·45	..
Potash	1·19	0·58	..
Lime	1·00	..	1·79
Magnesia	0·73	..	..
Water	..	..	2·07
	99·81	99·80	99·78

V. Imperfectly crystallized black mineral, occurring with the spodumene near Norwich, Massachusetts; probably decomposed triphylin.

The granite of Bodenmais must contain spodumene or some other mineral containing lithia, and the other alkalies would originate from decomposed felspar.

Phosphate of copper occurs hydrated as libethenite and phosphochalcite; the former associated with malachite, pyromorphite, grey copper ore, and tile ore in drusy cavities of mica-slate; the latter together with malachite, blue carbonate of copper, and red oxide of copper. The composition of these minerals varies very much as well as that of ehlite, olivenite, trombolite, which resemble them.

Phosphate of lead occurs combined with chloride of lead, as pyromorphite associated with other lead ores, and generally at the upper parts of lodes, less frequently in layers. Sometimes phosphate of lead is replaced by arsenate of lead or phosphate of lime, and the chloride of lead by fluoride of calcium. Fluorine and lime are always associated together in this mineral, and these varieties do not contain any arsenic acid. The pyromorphite of Langbanshytta, in Sweden, does not contain any phosphate of lead.

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[*] Baer.

[†] Rammelsberg.

Both galena and carbonate of lead undergo conversion into pyromorphite, and galena occurs pseudomorphous after pyromorphite.*

Chalcedony occurs as displacement pseudomorphs after pyromorphite, also brown hematite, silicate of zinc, and apatite.†

The nussierite occurring upon quartz in a mine at Beaujeu, Dép. du Rhone, appears to consist of chloride of lead, with five equivalents of phosphates and arsenates of lead, lime, and peroxide of iron.

Phosphate of uranium occurs, combined with phosphate of lime and water, in granite, in lodes traversing granite, gneiss and clay-slate, and in the cavities of amygdaloid rocks.

It also occurs combined with phosphate of copper, as chalkolite in the granite of Cornwall.

The criptolite occurring in the apatite of Arendal is a phosphate of cerium, lanthanium and didymium, with a small quantity of protoxide of iron.

The monacite of the Ural is probably the same mineral.

R.—SULPHATES.

Sulphate of iron occurs in hollows of old mines, especially those in clay-slate and shale. Blum mentions an instance of the occurrence of sulphate of iron with the form of iron pyrites, and Breithaupt states that apatite occurs with the form of sulphate of iron at Schlaggenwalde, in Bohemia.

Sulphate of iron also occurs, combined with sulphate of lime and magnesia, as botryogen, forming a crust upon gypsum and iron pyrites at Fahlun.

Persulphate of iron occurs, combined with water and small quantities of alumina, lime, and magnesia, as coquimbite in Chili, in a felspathic rock. Also combined with sulphate of potash, in the brown coal beds of Kolosoruth, near Bilin; and combined with sulphate of soda, near Modum, in Norway.

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* Blum.—Die Pseudomorphosen, p. 178; Nachtrag., 93.—Kenngott—Chem. pharm., Centralblatt, 1853. No. 36.

† Sillem.—N. Jahrb. für Mineral. 1848, p. 338.

Sulphate of zinc occurs at some places, probably as a product of the oxidation of blende.

Sulphate of copper occurs in fissures and hollows of old mines. Coquimbite sometimes contains sulphate of copper; basic sulphate of copper occurs mixed with silicate of copper, as a green earthy coating upon metallic copper at Valparaiso.

The brochantite occurring with malachite and red oxide of copper at Ekatherinburg, in Siberia; with galena and copper ores at Rezbanya, in Hungary; at Kirsuvig, in Iceland, and disseminated through sandstone in Mexico, is a basic sulphate of copper, with five equivalents of water. It also contains 3·15 to 8·18 per cent. oxide of tin, and 0·03 to 1·05 per cent. oxide of lead.

Lettsomite is probably a mixture of hydrated sulphate of copper and sulphate of alumina.

Sulphate of lead occurs in lodes, together with galena and carbonate of lead; also in cavities. It is sometimes pseudomorphous after galena.

Leadhillite consists of sulphate of lead, with three equivalents carbonate of lead. The sulpho-carbonate of lead consists of equal equivalents of the same constituents.

Caledonite consists of sulphate and carbonate of lead and oxide of copper. These minerals are probably intermediate products of the conversion of sulphate of lead into carbonate.

The linarite occurring at Leadhills in Scotland, and at Linares, in Spain, consists of equal equivalents of sulphates of lead, copper, and water.

Linarite undergoes conversion into carbonate of lead.

*Sulphate of nickel** occurs as a crystalline incrustation in the Wallace mine at Lake Huron.

Sulphate of cobalt occurs in old mines together with earthy cobalt and arsenate of cobalt.

Sulphate of uranium occurs as a basic salt, coating the uranium ores at Joachimsthal, in Bohemia.

S.—CHLORIDES, BROMIDES, IODIDES, AND FLUORIDES.

Only the more sparingly soluble of these compounds occur native, and the only corresponding hydrogen compound that has been met with is hydrochloric acid, and that only in the exhalations of volcanoes.

Chloride of copper occurs, combined with water and oxide of copper, as atacamite upon lodes of copper and silver ore in Chili, Peru, and at Schwarzenberg, in Saxony; also as an incrustation upon the sides of fissures in the lava of Vesuvius and Monte Rossi at Etna.

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* Haidinger.—Jahrb. der k. k. geol. Reichsanstalt, ii, 79.

Chloride of lead occurs as cotunnite in the crater of Vesuvius. The mendipite occurring near Churchill, in Somersetshire, contains chloride of lead, and two equivalents oxide of lead. Matlockite consists of equal equivalents of chloride and oxide of lead.

The chlorocarbonate of lead occurring upon galena, and in the volcanic sand at Vesuvius, consists of equal equivalents of chloride and carbonate of lead. This mineral has probably been deposited from water containing a soluble chloride and carbonate of lead dissolved by carbonic acid.

Chloride of silver occurs as horn silver in Peru and Saxony. It sometimes contains sulphuric acid, probably originating from sulphide of silver; but as this is also accompanied by peroxide of iron, it may originate from iron pyrites.*

There can be no doubt that sulphide of silver is, like all other sulphides, liable to oxidation. This is, indeed, indicated by the decomposition of brittle sulphide of silver.† Sulphide of silver is very often associated with horn silver, and it is very likely that water containing oxygen and chloride of sodium may have effected the conversion of the sulphide into chloride. The fact that a Zacatecas, in Mexico, horn silver occurs only in the upper part of the lodes is in favour of the opinion that it originates from sulphide of silver.

Proust found the silver coin from a sunken vessel, coated with chloride of silver, and Pallas found old Tartar coins in Siberia imbedded in a saline earth, either wholly or partially converted into chloride of silver. Horn silver occurs chiefly with native silver, and in Chili constitutes large masses, with nuclei of metallic silver, so that it may also be produced by the action of water containing chlorides, upon metallic silver.

Bromide of silver occurs associated with native silver in Mexico and Brittany. It appears in some instances to be reduced to the metallic state.‡

Malaguti and Durocher consider that the silver existing in sulphides cannot be in the state of chloride or bromide, because the sulphides of zinc, cadmium, bismuth, lead, tin, and copper, as well as the arsenides of antimony and cobalt, decompose chloride and bromide of silver. This decomposition goes on but slowly, except when the chloride or bromide is dissolved. The native sulphides present considerable differences as regards this decompsoition, probably owing to the presence of small quantities of foreign sulphides or arsenides, or to differences in the molecular constitution. Thus the very pure crystallized blende of Kongsberg is equally effective as artificially prepared sulphide of zinc, while the equally pure blende of Radna is only half as effective. The decomposing influence of sulphides is exercised in an equal degree upon bromide of silver, but is scarcely perceptible with iodide of silver.

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* Woulse.—Versuche über die Misch. einiger Mineralien, 1778. Torb Bergman.—Crell's Chem. Annal., 1784, p. 377.

† See ante, p. 65.

‡ Blum.—Op. cit., 2^{ter} Nachtrag, p. 15.

The embolite occurring upon calc-spar, and coated with native silver, in a very ferruginous limestone at Copiapo, in Chili, consists of two equivalents bromide of silver and three equivalents chloride of silver.

Iodide of silver occurs, together with native silver and chloride of silver, at Albarrodon, in Mexico and at Coquimbo.

Iodide of mercury is said to occur in Mexico.

Fluoride of cerium occurs as fluocerite in the granite at Broddbo and Finbo, in Sweden. A basic hydrated fluoride occurs imbedded in the felspar at Fahlun.

The yttrocerite imbedded in the quartz at the above places and in Massachusetts consists of the fluorides of cerium, yttrium, and calcium.

It is remarkable that no other metallic fluorides occur as minerals, although those compounds are, for the most part, sparingly soluble.

T.—Metallic Oxides.

Oxide of tin occurs as beds and masses in the older crystalline rocks, as a constituent of some varieties of granite, and disseminated through porphyry and mica-slate, as well as in lodes traversing granite, hornblende-slate, and clay-slate, and in alluvial deposits, together with other products of the denudation of rocks.

Quartz is always associated with tin ore, and is principally of prior origin. Klaproth found [*] in tin ore 0·75 per cent. silica, and Mallet [†] 0·84 per cent., but it does not appear to have been combined with the oxide of tin. Magnus found in brochantite

[*] Beiträge II., 245.

[†] Journ. of the Dublin Geol. Soc., IV., 272 —See also Berzelius.—Schweigger's Journ., XVI., 256.

8·2 per cent. oxide of tin that dissolved in hydrochloric acid, and the adjoining rock also contained traces of oxide of tin in the soluble condition.

Since tin ore melts to a glass when heated with clay, it might be expected that if granite were of igneous origin, the oxide of tin would have given rise to such a compound with the felspar; but this is not the case.

The relation between tourmaline and tin ore is remarkable, the latter being always abundant where the former is. The occurrence also of tin ore imbedded in tourmaline, in quartz druses, and cavities in topaz rock, shows that it has been deposited from water.

No minerals are known to occur pseudomorphous after tin ore, but it occurs pseudomorphous after felspar.*

Breithaupt † describes a white tin ore occurring in Cornwall, consisting of

Silica	51·57
Oxide of tin	38·91
Alumina	4·53
Peroxide of iron	3·55
Lime	0.16
Loss by ignition, etc.	1·28
	100·00

The admixtures of quartz, tin ore, and iron pyrites did not admit of any definite composition being ascertained; but the mineral is most likely a silicate of tin, perhaps a pseudomorph after felspar, in which the alumina had been replaced by oxide of tin. The small quantities of tin existing in many minerals, also containing silica, may also exist in the slate of silicate of tin.

The precipitate obtained by mixing solutions of stannate of potash and silicate of potash, and passing carbonic acid through the liquid, is not decomposed by sulphuretted hydrogen. The stannic acid precipitated from stannate of potash by hydrochloric acid, is, however, converted into sulphide by sulphuretted hydrogen; consequently, the former precipitate may be regarded as a compound of silica with oxide of tin. This silicate of tin dissolved in 164,000 parts of water, containing $\frac{1}{83}$ carbonate of potash, and in 123,614 parts of pure water.

The solubility of oxide of tin in alkaline carbonates, is well known, and even the native oxide of tin dissolves sufficiently to be recognizable by sulphuretted hydrogen.

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* English edition, ii, 175.

† Poggend. Annal., lxix, 435.

Artificially prepared stannate of lime dissolves in 111,547 parts of pure water. It resembles silicate of magnesia in being decomposed by carbonic acid only when dissolved, and not when merely suspended in water. It is also decomposed by sulphuretted hydrogen.

These observations lead to the conclusion that the oxide of tin occurring in rocks, may be dissolved by water containing alkaline and earthy carbonates, and these substances would be produced by the decomposition of granite, in which oxide of tin chiefly occurs.

The occurrence of tin ore in quartz veins, or together with quartz, shows distinctly that the deposition of quartz and tin ore were co-ordinate processes. In the tin ore deposits at Altenberg, the adjoining rocks appear silicified; but the lodes do not contain much quartz. The porphyry and gneiss are converted into hornstone; the granite into a mixture of quartz, mica, and tin ore. The same alteration of the granite is presented at Geyer and at Johangeorgenstadt. In most instances the silicified portions of the rocks adjoining deposits of tin ore are highly impregnated with tin ore. At Annaberg, Breitenbrunn, etc., there are lodes containing but little or no tin, and which are worked only for the sake of the adjoining rocks, through which the tin ore is disseminated. This shows clearly that the oxide of tin has not been transferred from lodes into the rocks adjoining, but the contrary.

The silica that has effected the silicification in these instances originated from the decomposed felspar, and this accounts for the diminution of this mineral in the altered porphyry, gneiss, and granite. Siliceous water coming from a distance may also have contributed to this alteration. The conversion of felspar into mica,* and its displacement by tin ore,† also elucidate the nature of the conversion of granite into the granular mixture of quartz, mica, and tin ore.

Titanic acid occurs as anatase in lodes and fissures in diorite, in cavities of mica-slate, fissures of gneiss, chlorite-slate, in deposits of magnetic iron ore, and in alluvial deposits.

It also occurs as rutile in gneiss, mica-slate, chlorite-slate, granite, diorite, granular limestone, and magnetic iron ore, in the sand of rivers and in surface deposits.

The brookite occurring with anatase at Oisans and at Snowdon, in Wales, is also titanic acid. That from the Ural contains 4·5 per cent. peroxide of iron.‡

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* English edition, ii, 111.

† Ibid, ii, 175.

‡ H. Rose, Pogg. Ann., lxi, 507.

The arkansite of Magnet cave, Arkansas, is also pure titanic acid.

Oxide of tungsten occurs in small veins traversing quartz at Huntington, Connecticut, accompanied by wolframite and scheelite, from which it has most likely originated.

Oxide of molybdenum occurs as a coating upon sulphide of molybdenum as a product oxidation.

Oxide of tellurium occurs in Transylvania, in cavities of the quartz, containing native tellurium disseminated through it.

Oxide of chromium occurs as a coating and in cavities of chrome iron ore, and in decomposed rocks. It also occurs combined with oxide of iron as chrome iron ore, as nests, veins, and beds in serpentine and talcose rocks, also mixed with sand.

The chrome iron ore at Texas, Chester Co., is traversed by hydrocarbonate of nickel, and contains 2·28 per cent nickel.

Vanadic acid is said to occur as an incrustation on the native copper of the Cliff mine, lake Superior.*

Oxide of antimony occurs in lodes traversing gneiss, mica-slate, and grauwacke, together with other compounds of antimony. It is sometimes a product of the oxidation of metallic antimony, as at Allemont, in the Dauphinée, and it is also a product of the oxidation of sulphide of antimony.

The antimony ochre occurring in lodes traversing mica-slate, etc., consists of oxide of antimony combined with antimonic acid, its composition being tolerably constant.

	I.	II.	III.
Antimony	79·51	80·64	..
Oxygen	20·49	19·36	..
Antimonic acid	..	..	52·48
Oxide of antimony	..	..	47·52
	100·00	100·00	100·00

Analysed by

I. Antimony ochre, containing 4·63 per cent. water, with traces of arsenic.

II. Antimony ochre of Pereta, in Tuscany. Bechi.

III. Calculated composition.

It is a product of the decomposition of sulphide of antimony. In this alteration there would be a diminution of weight to the amount of 8·98, and of volume to the extent of 20·7, which agrees with the frequently porous condition of the crusts of antimony ochre.

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* Teschemacher.—Sillim. Amer. Journ. (2), XI., 223.

Oxide of antimony also occurs, combined with two equivalents of sulphide of antimony, as red antimony, in lodes traversing gneiss, mica-slate, clay-slate, and in brown iron ore lodes. This is an intermediate product of the conversion of sulphide of antimony into oxide of antimony.

The frequent occurrence of antimony with other metals, and of sulphide of antimony with other sulphides, would lead to the expectation that, by the oxidation of these compounds, antimonates would often be produced. The decompositions of red silver ore, brittle sulphide of silver, grey copper ore, and bournonite show, indeed, that such oxidation does take place. However, antimonates do not occur native, and perhaps this may be due to the tendency towards the production of antimonate of antimony.

Arsenous acid occurs in lodes accompanying arsenides of cobalt, lead, silver, etc.; it is rarely crystalline, but has more the character of an incrustation, showing its origin from solution. It is a product of the oxidation of arsenides, frequently, as it would seem, of mispickel and also of realgar.

Oxides of iron occur in a variety of conditions, some of which have already been referred to. They are more abundant than any other metallic oxide, both in lodes and beds. Oxide of iron is in all instances the product of decomposition of ferruginous minerals, and since almost all minerals constituting rocks contain some iron, it may originate from the most diverse sources.

Next to quartz and the various other modifications of silica, there is no substance that occurs pseudomorphous after so many mineral substances as oxide of iron.

Displacement pseudomorphs of red hematite after calc-spar occur near Sundwig, in Westphalia,* in fissures of the transition limestone, which are filled with compact red hematite, and specular iron ore and quartz. The pseudomorphs sometimes contain a nucleus of calc-spar. They are covered with scaly red iron ore, and never project clear beyond the matrix, but are imbedded. A thick lode-shaped mass of calc-spar occurring at the same place, renders it probable that the crystals from which these pseudomorphs were produced were originally imbedded in a crystalline matrix of calc-spar.

At the Gottsegne mine, in the Erzgebirge, there are very fine pseudomorphs of this kind, and Blum mentions many other localities where red hematite occurs as displacement pseudomorphs after calc-spar.

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* v. Dechen.—Das Gebirge im Rheinland Westphalen, II., 40.

Sillem * mentions the occurrence of sphærosiderite rhombohedrons at Stolberg, in the Harz, which consist chiefly of peroxide of iron that has become hydrated at the edges and corners.

Brown hematite also occurs as a displacement pseudomorph after calc-spar.

The frequent occurrence of red and brown hematite in limestone, the transition of one into the other, and the presence of the same fossil remains in the iron ores as in the limestone, leads to the conclusion that many deposits of limestone have originated by the displacement of the carbonate of lime.

Haidinger describes red hematite that is pseudomorphous after crystallized brown hematite. The presence of small nodular masses of brown iron ore imbedded in the mass, shows that the alteration cannot have been effected by the action of heat, but must have taken place at the ordinary temperature.

Oxides of manganese are also of very frequent occurrence, and as regards their origin, present a close correspondence with oxides of iron.

Grey oxide of manganese occurs as manganite, both crystallized and as compact masses in lodes, traversing various rocks, in drusy cavities, and in deposits of iron ores. It consists of—

	I.	II.	III.	IV.
Manganese	62·78	62·86	62·68	62·77
Oxygen	27·14	27·64	27·22	27·13
Water	10·08	9·50	10·10	10·10
	100·00	100·00	100·00	100·00

For the sake of comparison with other oxides of manganese, the amounts of protoxide of manganese and of surplus oxygen are given below—

	I.	II.	III.	IV.
Protoxide of manganese	80·99	81·10	80·86	80·98
Oxygen	8·93	9·40	9·04	8·92
Water	10·08	9·50	10·10	10·10
	100·00	100·00	100·00	100·00

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* Breithaupt.—Paragenesis, p. 228.

	Analysed by
I. Manganite of Undenaes in Westgothland	Arfwedson.*
II. Manganite of Ilefeld	L. Gmelin.†
III. and IV. Manganite of Ilefield	Turner.‡

Water extracted from the carefully picked mineral No. IV, traces of chloride of calcium, sulphates of lime and soda. It dissolved, however, in hydrochloric acid, without leaving any residue, and did not contain any silica, lime or baryta.

This mineral has been regarded as hydrated sesquioxide of manganese, but when covered with hydrochloric acid, it evolves some chlorine, especially on the application of heat. Hence it either contains some binoxide of manganese, or is decomposed into binoxide and a lower oxide, in the presence of hydrochloric acid. Probably it may be regarded as a saline compound of binoxide of manganese, with the protoxide and other bases.

In the above analyses the proportion of the oxygen in the protoxide to the whole oxygen in the mineral, is as follows—

18·21 : 27·14; 18·24 : 27·64; 18·18 : 27·22; 18·21 : 27·13 or nearly as 2 : 3.

The difference between the two quantities is nearly the same as the quantity of oxygen in the water. Hence the composition of manganite may be represented as—

Manganese	62·56	Protoxide	80·71	Protoxide	40·35	= 1
Oxygen	27·22	„	9·07	Peroxide	45·43	= 1
Water	10·22	„	10·22	Water	10·22	= 1
	100·00		100·00		100·00	

Thus both oxides would contain equal quantities of manganese, and the oxygen in the binoxide amounts to twice as much as in the protoxide.

Manganite occurs pseudomorphous after calc-spar, which is sometimes incrusted, and sometimes entirely displaced.§ In the porphyry dykes at Ilefield, there are druses in which the calc-spar crystals consist partly of manganite and partly of carbonate of lime.

The manganite occurring in limestone may indeed be, in most instances, the result of displacement of carbonate of lime, by a solution of bicarbonate of manganese, which underwent partial oxidation, so as to produce grey oxide of manganese.

[*] Schweigger's Journ., xxvi, 262, und xlii, 208.

[†] Poggend. Annal., xiv, 221.

[‡] Transact. of the Geog. Soc. of Edinb., f. 1827.

[§] Voigt.—Leonhard's Taschenbuch für Mineral., xv, 918; Blum.—Op. cit., p. 261.

Manganite also seems to originate from protosilicate of manganese; for instance, rhodonite and manganese-epidote. At Ekatherinburg, in the Ural, it is associated with the former mineral [*] and at St. Marcel, with the latter.

Psilomelan occurs, together with other manganese ores, in fissures of various rocks, even in clay, and most frequently in iron-ore lodes. It generally presents stalactitic nodular forms, but also occurs as compact masses.

	I.	II.	III.	IV.	V.	VI.
Protoxide of manganese	69·80	70·97	70·3	70 3	81·8	81·36
Oxygen	7·36	7·26	7·2	6·7	9·5	9·18
Baryta	16·36	16·69	16·5	12·8	..	..
Potash	..	..	..	...	4·5	3·04
Soda and magnesia ..	..	..	..	..	..	0·32
Lime	..	..	..	..	..	0·38
Oxide of copper ..	..	..	..	..	..	0·96
Peroxide of iron ..	..	..	..	..	..	1·43
Silica	0·26	0·95	..	..	..	0·54
Insoluble	..	..	2·0	5·6	..	..
Water	6·22	4·13	4·0	4·6	4·2	3.39
	100·00	100·00	100·0	100·0	100·0	100·60

	Analysed by
I. Psilomelan of Schneeberg	Turner.[†]
II. Psilomelan of la Romanèche	
III. Compact psilomelan	Berthier.[‡]
IV. Earthy psilomelan	
V. Psilomelan of Beireuth	Fuchs.[§]
VI. Psilomelan of Horhausen	Rammelsberg.[‖]

In the analyses Nos. I, II, and V, the oxygen was not estimated directly, but from the loss by heating to whiteness, after deducting the water. For this reason the manganese is put down as protoperoxide.

VII, VIII, IX. Psilomelan of Ilmenau.

VII. Compact psilomelan	Aausbruch.[¶]
VIII. Compact psilomelan	Herter.[**]

[*] G. Rose.—Reise nach dem Ural. i, 164.

[†] Transact of the Roy. Soc. of Edinburgh, for 1827.

[‡] Annal. des Mines, vi, 291.

[§] Schweigger's Jour., lxii, 255.

[‖] Handwörterbuch. Abtheilung, ii, p. 73.

[¶] Rammelsberg Handwörterbuch. Supplement ii, p. 121.

[**] Ibid., Suppl., iv, 191.

	VII.	VIII.	IX.	X.
Protoxide of manganese	77·28	74·61	76·08	70·60
Oxygen	15·82	16·06	15·36	14·18
Baryta	0·12	2·40	4·16	6·55
Potash	5·29	0·92	3·71	4·05
Lime	0·91	1·84	..	..
Magnesia	..	0·64	..	1·05
Oxide of copper	0·40	0·46	..	..
Peroxide of iron	..	..	..	0·77
Silica	0·52	..	0·83	0·60
Water	..	2·70	..	1·67
	100·29	99·63	100·14	99·47

	Analysed by
IX. Compact and partially columnar psilomelan	Rammelsberg.*
X. Dark grey fibrous soft psilomelan	Ebelmen.†

	XI.	XII.	XIII.	XIV.
Protoxide of manganese	68·00	78·90	61·82	70·17
Oxygen	13·62	12·02	16·41	15·16
Baryta	8·59	..	15·34	8·08
Potash	0·27	0·27	0·28	2·62
Lime	0·20	..	0·59	0·60
Magnesia	0·53	..	0·28	0·21
Oxide of copper	0·36	..	..	0·30
„ cobalt	..	..	0·03	0·54
Peroxide of iron	..	4·40	2·70	..
Alumina	..	..	0·75	..
Silica	2·18	..	0·91	0·90
Water	3·95	4·38	..	1·43
	97·70	9·97	99·11	100.01

	Analysed by
XI. Scaly psilomelan of Schwarzenberg, in the Erzgebirge	Heyl.‡
XII. Compact scaly psilomelan of Eisern, near Siegen	Schnabel.§
XIII. Coarse greyish-black psilomelan of Skidberg, in Sweden	Bahr.‖

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* Rammelsberg Handwörterbuch, Suppl. v, 196.

† Ann. des Mines (3), xix, 155.

‡ Suppl. IV., p. 191.

§ Suppl. IV., p. 191.

‖ Journ. für pract. Chemie., liii, 312.

	Analysed by
XIV. Nodular and rather hard psilomelan of Heidelberg	Rammelsberg.[*]

These analyses show that binoxide of manganese, baryta and potash, are the essential constituents of psilomelan.

Fuchs showed that the potash is not extracted by boiling water, unless the mineral has been previously heated to redness. Berthier states that some baryta is also extracted by water from the ignited mineral. Hence, both bases seem to be combined with the binoxide of manganese. I have confirmed these observations, and found also that the compound of binoxide of manganese with potash and baryta, is exceedingly difficult to decompose completely by heat.

Similar compounds of binoxide of manganese with baryta and potash, may be produced artificially, and they present the same characters as psilomelan.

From the affinity which binoxide of manganese seems to have for these bases, it probably decomposes the carbonate of potash and baryta in the water of springs, etc. This is the more likely since the decomposition of these carbonates by pyrolusite may be effected artficially. In this respect binoxide of manganese presents the characters of an acid, and this is the case not only in psilomelan but also in other manganese ores, earthy cobalt, etc.[†] The alkaline reaction that appears after ignition of psilomelan shows that by the partial reduction of the binoxide of manganese the compound is decomposed, and this shows that psilomelan is not, as Turner considered, a compound of sesquioxide of manganese and baryta, but is more probably a mixture of binoxide of manganese with a smaller proportion of a compound of binoxide of manganese with potash and baryta.

Psilomelan does not appear to have originated from manganese spar, but was more likely deposited from water containing carbonate of manganese, baryta, and potash. The other bases present in psilomelan are probably in combination with the binoxide of manganese.

If all the manganese in psilomelan is in the state of binoxide, then, as the binoxide contains twice as much oxygen as the protoxide, the excess of oxygen found by analysis ought to be equal to that in the protoxide. In the following table the quantities of oxygen in the protoxide of the respective minerals are given opposite A, and the excess of oxygen opposite B:—

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[*] Suppl. III., p. 99.

[†] H. Rose.—Poggend. Annal., lxxxiii, 133.

	I.	II.	III.	IV.	V.	VI.	VII.
A. ..	14·73	14·98	14·84	14·84	17·27	16·27	17·37
B. ..	11·65	11·62	11·52	11·52	14·52	15·08	15·82
Difference	8·08	3·36	3·32	3·32	2·75	1·19	1·55

	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
A. ..	16·78	17·11	15·88	15·29	17·74	18·90	15·78
B. ..	16·06	15·36	14·18	13·62	12·02	16·41	15·16
Difference ..	0·72	1·75	1·70	1·67	5·72	2·51	0·62

Hence it would seem that there is generally some protoxide of manganese present, probably combined with binoxide of manganese, in the same manner as baryta, potash, etc. This is rendered more probable from the fact that pyrolusite decomposes carbonate of manganese when heated with it and water to 212° F., without access of air.

Psilomelan occurs pseudomorphous as a coating upon heavy spar, which has in some instances been removed.* Near Schöllgrippen, in Spessart, it occurs as a coating on cube ore.† The cubical pseudomorphs mentioned by Friesleben most likely originate from fluor-spar.‡

Sesquioxide of manganese occurs as braunite, both crystallised and as amorphous masses of granular texture, sometimes accompanied by psilomelan and pyrolusite.

	I.	II.
Protoxide of manganese	86·94	..
Manganese	..	67·39
Oxygen	9·85	29·40
Baryta	2·62	2·62
Water	3·95	0·95
Silica	trace	..
	100·36	100·36

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* Blum.—Op. cit., p. 265. † Ibid, p. 266. ‡ Ibid, p. 226.

I. Braunite of Elgersburg — Analysed by Turner.*
II. Calculated composition.

Here the proportion of oxygen in the protoxide to the whole quantity is as 19·55 : 29·40, or nearly as 2 : 3. Hence the calculated composition of braunite is—

Manganese	69·68	Protoxide	89·89	....	44·95	I
Oxygen	30·32	....	10·11	Binoxide	55·05	I
	100·00		100·00		100·00	

And the amount of manganese is the same as in manganite. The 2·62 per cent. of baryta would require 1·49 parts of binoxide of manganese, corresponding to 1·22 parts protoxide, which is to be deducted from 44·95. In this case the composition of the above braunite would be—

Protoxide of manganese	43·13	95·95
Binoxide	52·82	
Baryta	2·58	4·05
Binoxide of manganese	1·47	
	100·00	100·00

Braunite occurs pseudomorphous after manganite.† The conversion of rhodonite into braumite has been already referred to.‡

Hausmannite consists of a compound of sesquioxide of manganese with protoxide of manganese. It occurs in lodes, both crystallized and compact, sometimes mixed with psilomelan and pyrolusite.

	I.	II.
Protoxide of manganese	92·82	92·49
Oxygen	6·29	7·00
Baryta	0·11	0·15
Silica	34	..
Water	44	..
	100·00	98·64

I. Hausmannite of Ilefeld. — Analysed by Turner.§

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* Loc. cit.

† Breithaupt.—Paragenesis, p. 198.

‡ English edition, ii, 327.

§ Transact. of the Roy. Soc. of Edinb. 1827.

	Analysed by
II. Hausmannite of Ilefeld, crystallized	Rammelsberg.*

Here the oxygen of the protoxide is to the whole amount nearly as 3 : 4, and hence, according to Rammelsberg's analysis, hausmannite is anhydrous, consisting of—

Manganese....	72·10	Protoxide	93·03	....	62·02	2
Oxygen	27·90	....	6·97	Binoxide	37·98	1 †
	10·000		100·00		100·00	

Hausmannite occurs pseudomorphous after manganite.‡ This alteration would consist essentially in the separation of water. Perhaps these pseudomorphs may consist in part of braunite.

Hausmannite also occurs as a displacement pseudomorph after calc-spar.§

Binoxide of manganese occurs as pyrolusite both crystallized and in various other forms.

	I.	II.	III.	IV.
Protoxide of manganese	78·43	78·27	79·72	81·91
Oxygen	19·71	17·57	17·56	17·47
Baryta	..	0·53	0·57	..
Protoxide of iron and alumina	..	..	..	0·17
Silica	..	0·51	0·55	0·13
Water	1·86	1·12	1·57	0·32
	100·00	98·00	99·97	100·00

	Analysed by
I. Pyrolusite of Andenaes, in Sweden	Arfwedson.‖
II. Compact columnar pyrolusite of Elgersburg	Turner.¶
III. A similar mineral	
IV. Polianite of Plutten, in Bohemia	Plattner.**

The amounts of oxygen belonging to protoxide in these minerals were—

I.	II.	III.	IV.
17·64	17·60	17·93	18·42

As the amounts in Nos. II, III, and IV, agree nearly

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[*] Handwörterb., p, 294.

[†] H. Rose.—Poggend. Annal., lxxxiii, 113.

[‡] Blum.—Op. cit., p. 169.

[§] Herbst.—Jahrb. für Mineral, 1842, p. 435.

[‖] Loc. cit., p. 210.

[¶] Loc. cit.

[**] Poggend. Annal., lxi, 192.

with those of surplus oxygen, they may be regarded as pure binoxide of manganese, a small portion of which is combined with baryta.

Pyrolusite occurs pseudomorphous after manganite,[*] also as displacement pseudomorphs after calc-spar,[†] bitter-spar,[‡] and calamine.[§]

This mineral has, in most instances, been produced by the peroxidation of carbonate of manganese dissolved in water, and most likely, also, by the peroxidation of other oxides of manganese. The presence of baryta in pyrolusite[||] renders it probable that it has sometimes originated from psilomelan.

Binoxide of manganese also occurs, combined with water, as wad, in a variety of forms, together with other ores of manganese and iron. It contains from 1 to 8 per cent. baryta, also lime, magnesia, peroxide of iron, and alumina. Wackenroder found in one variety 8 per cent. oxide of lead, with small quantities of copper and cerium, and 31·3 per cent. water.

	I.	II.
Protoxide of manganese	66·5	67·50
Oxygen	12·1	13·48
Baryta	8·1	0·36
Potash	..	3·66
Lime	..	4·22
Peroxide of iron	1·0	1·01
Silica	2·5	0·47
Water	9·8	10·30
	100·0	100·00

	Analysed by
I. Wad of Ilmenau	Scheffler.[¶]
II. Wad of Rübeland, in the Harz	Rammelsberg.[**]

There cannot be much protoxide of manganese in either of these varieties.

Binoxide of manganese also occurs, combined with alumina and peroxide of iron, as a blackish-blue mineral at Kalteborn, near Siegen.

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[*] Haidinger.—Poggend. Annal. xl, 374—Blum—Op. cit. p. 168. Breithaupt —Poggend. Annal. lxi, 187.

[†] Blum.—Op. cit. p. 258.

[‡] Berthier.—Ann. de chim. et phys., li, 79.

[§] Ibid., 2te Nachtrag, p. 109.

[||] Archiv. der Pharmacie, xxxv, 260.

[¶] Archiv der Pharmacie, xxxv. 260.

[**] Poggend. Ann., lxii, 157.

Judging from the proportion of the oxygen in this mineral, and that corresponding to protoxide of manganese, it would contain only a small amount of protoxide. The alumina could not be dissolved out by nitric acid after the deoxidation of the manganese, so that it, as well as the peroxide of iron, was most likely combined with the binoxide of manganese. It is worth noticing that the proportion of the oxygen of the bases, to that of binoxide of manganese in this mineral is nearly as 1 : 2, or the same as in manganite.

The analyses of iron-spar show the presence of manganese in very small proportion, but the average quantity is sufficient to give rise to the production of manganese ores as a product of the decomposition of iron-spar, and the deposits of manganese ore, thus produced, would amount to one-tenth the mass of the deposits of brown hematite, or one sixth those of red hematite produced at the same time.

E. E. Schmidt * describes the occurrence of brown hematite, accompanying the ordinary manganese ores in the porphyry, at Ilmenau. Two varieties of it had the following composition—

	Yellow.	Red.
Peroxide of iron	74·96	75·00
Sesquioxide of manganese	1·82	1·33
Alumina	1·32	1·51
Silica	2·51	5·02
Water	15·67	14·10
	96·28	95·96

The deficiency consisted of carbonates of lime, magnesia, alkalies, antimony and lead.

Most likely these minerals, which consist essentially of hydrated peroxide of iron, were produced by the decomposition of porphyry ; during which, greater part of the manganese was removed and deposited elsewhere as manganese ore.

Fresenius † has shown that bicarbonate of manganese is not decomposed by atmospheric oxygen, like bicarbonate of iron, but that the carbonate of manganese is deposited in consequence of the disengagement of carbonic acid. Therefore while the iron

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* Poggend. Annal. lxxxiv. 495.

† Jahrb des Vereins für Naturkunde in Nassau vi., 160.

would be deposited as hydrated peroxide, it would be separated from the manganese, which would be deposited as carbonate elsewhere, and subsequently peroxidized. The amount of hydrated peroxide of iron, in the water deposited by the warm springs at Wiesbaden, decreases in proportion to the distance from the spring, while the amount of carbonates of manganese, lime, and magnesia increases. This separation might be expected to take place to a still greater extent in the case of water at the ordinary temperature.

This view of the origin of manganese ores is supported by their association with iron ores in numerous localities, inasmuch as they are most abundant where the iron ores contain but mere traces of manganese ; as, for instance, in the Thuringian Forest, where the red hematite and manganese ores have originated from the decomposition of minerals containing silicate of iron and manganese.*

Oxide of zinc occurs combined with sesquioxides of manganese and iron, in beds in grauwacke, together with franklinite, at Sparta and Franklin, New Jersey.

Oxide of copper occurs with other copper ores, especially copper pyrites, and generally mixed with oxides of iron and manganese. It is said to occur as thin laminæ in the crater of Vesuvius. A conglomerate rock at Lake Superior contains rounded masses of black oxide of copper, sometimes accompanied by silicate of copper; and a lode in the conglomerate at Copper Harbour consists almost entirely of pure black oxide, with octahedral crystals of red oxide.

The surface of compact masses of sulphide of copper and copper pyrites, is sometimes coated with pulverulent black oxide of copper. Haidinger describes pseudomorphous oxide of copper after sulphide of copper.

Tile ore, a mixture of earthy oxide of copper and iron ochre, generally occurs together with copper pyrites.

Oxide of copper also occurs combined with oxide of manganese, as crednerite, in a brown hematite lode, traversing melaphyr conglomerate; also imbedded in psilomelan and hausmannite. It contains from 1 to 3 per cent. baryta, and traces of vanadium.†

A similar compound occurs together with tin ore at Schlackenwald, in Bohemia, and at Kamsdorfen, Thuringia, containing small quantities of nickel, cobalt, iron, etc., as stalactitic masses, which indicate deposition from water containing products of the decomposition of manganese and copper ores.

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* English edition, ii, 325.

† Jahrb. für Mineral., etc., 1847, p. 5.

The red oxide of copper often occurs together with other copper ores in the above-mentioned localities, in amygdaloid rocks, and as a coating of the lava at Vesuvius. This oxide sometimes undergoes reduction to the metallic state, furnishing porous pseudomorphs, as in the amygdaloid rock at Oberstein,* and at Nischne Tagilsk, in the Ural.† In this alteration the diminution of weight would be 11·22, and that of volume 39·96.

Red oxide of copper also undergoes conversion into malachite.‡ These pseudomorphs are rarely hollow, but, on the contrary, have their faces bulged, which agrees with the fact that in this alteration there would be an increase of weight to the extent of 154·75, and of volume to the extent of 235·17. In any case, however, some portion of the malachite must have been removed during the alteration.

Brown hematite and, sometimes also, stilpnosiderite occur as displacement pseudomorphs after red oxide of copper.

Oxide of lead occurs somewhat abundantly in the ravines of two volcanoes in Mexico, also together with carbonate of lead in the fissures of a quartz vein at Bolanos, in Mexico.

Red oxide of lead occurs in galena and calamine. The pseudomorphs of this substance after galena and carbonate of lead, indicate the mode of its production.

Binoxide of lead also occurs together with carbonate of lead, pyromorphite and sulphate of lead.

Oxide of bismuth occurs together with native bismuth, but generally mixed with oxides of iron, copper, and arsenic; sometimes also imbedded in quartz. It originates from the decomposition of needle ore, as is shown by the pseudomorphs after this mineral.§

Oxide of cobalt occurs in lodes of cobalt ores, principally associated with arsenide of cobalt. It is a mixture of peroxides of manganese and cobalt, oxide of copper, iron, baryta, and lime. The yellow and brown earthy cobalt at Kamsdorf is a mixture of hydrated arsenate of iron, oxide of cobalt and lime. It may, therefore, be inferred that the earthy cobalt which does not contain arsenic has originated from such a mixture, and that manganese has been introduced. The presence of baryta and lime would appear to indicate the agents by which this alteration had been effected.

The lavendulan occurring in lodes with arsenide of cobalt and

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[*] Blum.—Op. cit., p. 19.

[†] Breithaupt.—Berg-und Hüttenmannische Zeitung, 1853. No. 23.

[‡] G. Rose.—Reise, etc., i., 270.

[§] G. Rose.—Reise nach dem Ural I. 197.—Blum—Op. cit., p. 173.

iron pyrites, contains arsenic acid, oxides of cobalt, nickel, and copper, with water, and has probably been produced from arsenide of cobalt, as this mineral often contains copper.

Oxide of uranium occurs as pitchblende in lodes traversing gneiss; also in granite and grauwacke. It also occurs hydrated, as uranium ochre.*

The coracite of Lake Superior contains oxides of uranium, lead and iron, with lime, silica, and carbonic acid.

U.—NATIVE METALS.

Gold occurs in lodes of quartz, brown hematite, and iron pyrites; in clay-slate, grauwacke, mica-slate, hornblende-slate; in granite, gneiss, syenite, quartzose porphyry, gabbro, diorite, diabase, aphanite, serpentine, and dolomite; in the gravel and sand of rivers, as nuggets, laminæ, and dust, generally accompanied by quartz, brown hematite, zircon, magnetic oxide of iron, iserine, spinell, etc.

In Chili all the gold is obtained from detrital deposits, originating from the denudation of the upper parts of lodes. The occurrence of gold as small crystals and as capillary masses, is indicative of processes of reduction from compounds, and its frequent occurrence in quartz indicates the deposition of such gold compounds from the water that deposited the quartz.

It is, however, difficult to imagine what state of combination the gold could exist in.

All native gold contains silver, which, in electrum, amounts to 36 per cent.; but even in this instance there does not appear to be any definite proportionality.

Many minerals contain minute traces of gold, especially galena, copper pyrites, and iron pyrites. It cannot be determined whether this gold exists in the state of sulphide, though it is probable such is the case. When such auriferous minerals are decomposed by oxidation, the gold would be eliminated, removed by water, and accumulated in alluvial deposits. In Chili, quartz, brown hematite, and specular iron ore, are the only minerals occurring at the outcrop of the auriferous lodes, and it is precisely these minerals that are associated with gold in alluvial deposits.

There seems to be an intimate connection between gold and iron, either in the state of sulphide or oxide, and likewise between quartz and gold. A silicate of gold may be prepared artificially, and it appears that under certain circumstances it may be dissolved in sensible amount. The silica constituting the quartz associated with gold, certainly originates from the decomposition of silicates in rocks, and it may be conjectured that the gold has the same origin, possibly existing as silicate.

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* Scheerer.—Poggend. Annal., lxxxix, 1.

Gold also occurs combined with mercury as native amalgam.

Platinum occurs nearly pure, mixed with particles of palladium, in Brazil; also in combination with several other metals, and accompanied by osmium-iridium, gold, titaniferous iron ore, chrome iron ore, spinell, and quartz, in South America and Russia. It generally occurs in alluvial deposits, more rarely in brown hematite and quartz veins traversing decomposed syenite, greenstone, or serpentine.

This metal, like gold, appears to have been deposited from water containing soluble compounds of platinum, and both the sulphides and silicate of platinum appear to have some degree of solubility.

It is worth while noticing that platinum is accompanied by iron in largest amount both as a constituent of the ore and in an oxidized state mixed with it. Hence it might be inferred that the water which deposited the oxide of iron also contained platinum in solution.

Iridium and *osmium* occur in platinum ore, and also combined together as an admixture with platinum ore. These two metals are the only ones which occur as oxides in combination with iron and chromium in the irite of the Ural.

Palladium and *rhodium* both occur in platinum ore. The former also occurs as crystals, together with native gold, at Tilkerode, in the Harz, in combination with gold in a sand containing specular iron ore, and in conbination with gold and silver.

Silver occurs native, generally as indistinct crystals, grouped together in a variety of forms. At Keweenaw Point and Isle Royale it is disseminated through trapp rock, and is always accompanied by native copper.*

Malaguti and Durocher† have shown that metallic sulphides, arsenides, oxides, and even native metals, associated with silver ores, or occurring near them, are always more or less argentiferous. Hence this metal appears to be very generally distributed.

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* Foster and Whitney.—Op. cit., p. 108.

† Comptes rendus, xxv, No. 4.

In most instances, native silver occurs upon sulphide of silver, and sometimes there are upon the threads of silver, small crystals of calc-spar or heavy-spar. In one instance, I observed a crystal of sulphide of silver upon one of the threads of silver. Sulphide of silver appears sometimes to have been reproduced from native silver, still presenting the thread-like shape, and sometimes containing a nucleus of silver.

Native silver sometimes presents impressions of calc-spar crystals, while at other places threads of silver project from the calc-spar, in the one instance having been deposited before, and in the other after, the silver. Impressions of quartz crystals also are sometimes found in native silver. Baryta-spar, fluor-spar, and iron-spar, also occur, intimately blended with native silver and sulphide of silver, in such a manner as to show that the latter was the original mineral. Native silver also occurs in heavy-spar, and hornstone, which appear to have been deposited round the silver, much in the same way that the deposit is formed on thorn faggots at salt works.

The association of native silver with other silver ores than sulphide of silver, is very much less frequent, and in many instances the production of metallic silver is probably preceded by the production of sulphide of silver. It appears sometimes to be produced from galena, but in many instances of the association of native silver with galena, this mineral is partly of subsequent production, and has been deposited round the threads of silver.

Artificially prepared sulphide of silver is reduced by water vapour, at a temperature below the melting point of zinc, and separated in the same thread-like forms that are met with in lodes. Native sulphide of silver is also reduced in a similar manner, as well as red silver ore, brittle sulphide of silver, polybasite, etc. Galena mixed with 27·3 per cent. artificial sulphide of silver, also yielded by this treatment, thread-shaped metallic silver; but the sulphide of silver was more easily reduced than any other of the above-mentioned minerals. Hence it would appear, that native silver may be produced in a similar manner, by the action of water vapour, more especially since it occurs most frequently with that silver ore which is most susceptible of this decomposition.

The removal of sulphide of silver from compound sulphides, presupposes oxidation of those sulphides, and, if in the above-mentioned reduction of sulphide of silver, the sulphur was oxidized by atmospheric oxygen, there would be some analogy between these two cases, the only difference being, that in the one case in consequence of a scanty supply of oxygen, the sulphur only was oxidized, and not the silver; while in the other case, where there was an abundant supply of oxygen, the silver also was oxidized, and removed as sulphate in solution.

The grey copper ore of Siegen contains on the average 0·568 per cent. silver. This silver contains from 0·017 to 0·07 per cent. of gold, so that taking the minimum quantity, the amount of gold in the grey copper ore would be only $\frac{1}{10,000}$. Assuming, in accordance with Pettenkofer, that this gold contains 0·2 per cent. of platinum, the amount of this metal in the grey copper ore would be $\frac{1}{5,000,000}$. If this platinum, again, was accompanied by the metals usually associated with it, the palladium, generally amounting to 1 per cent. in platinum ore, would, in the grey copper ore, amount to $\frac{1}{500,000,000}$. There is no difficulty in supposing such quantities of these metals to be dissolved together with other constituents of grey copper, in the solutions from which this mineral was deposited.

According to Malaguti and Durocher, sea-water contains about $\frac{1}{100,000,000}$ part of silver.

Silver occurs also in combination with mercury as native amalgam, together with native mercury and cinnabar. The arguerite occurring in lodes of heavy spar, together with native silver, chloride of silver, cobalt bloom, etc., at Argueros, in Chili, consists of six equivalents silver and one of mercury.

Silver occurs, combined with bismuth, copper, and arsenic, at San Antonia, in Chili, and in the Schapbach valley, in Baden.

Mercury occurs as globules and disseminated through rocks, also in cavities of cinnabar, fissures of clay-slate, carboniferous limestone, etc. It has probably originated for the most part from cinnabar by partial oxidation.

Copper occurs native very abundantly in lodes traversing various rocks. Sometimes it is crystalline, but more frequently amorphous. The fossil remains of fish from the cupreous slate of Mansfeld consist of metallic copper, and clearly indicate that it has been reduced from solution by organic substance.

Its occurrence in serpentine into which much organic substance has been introduced during its production by the metamorphime of other rocks also indicates a similar origin.*

Bismuth occurs native, together with cobalt and nickel ores, in lodes traversing the older rocks. It is frequently arsenical.

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* Silliman's Amer. Journ. (2), vii, 286.

Lead rarely occurs native. That in the cavities of volcanic rocks may have been produced by reduction at a high temperature; but its occurrence in galena, clay-stone, and in cavities of porphyry, cannot be accounted for in the same manner.

Antimony occurs native as crystalline granular masses in lodes traversing gneiss, clay-slate, grauwacke, and together with antimony ore in calc-spar veins. It frequently contains some silver, iron, or arsenic. Sillem[*] describes pseudomorphous antimony, after antimony bloom, occurring at Allemont, in the Dauphinée.

Arsenic occurs native in lodes of silver, lead, and cobalt ores. It has most likely originated from arsenous acid by reduction.

Tellurium occurs but rarely, in lodes traversing grauwacke.

Iron occurs native but rarely. The following analyses are the only ones that have been made:—

	I.	II.
Iron	92·5	91·8
Lead	6·0	..
Copper	1·5	..
Carbon	..	7·0
	100·00	98·8

Analysed by

I. Native iron from the Eiserner Johannes mine, at Gross Kamsdorf } Klaproth.[†]

It was a compact mass, weighing 12 ounces, imbedded in hydrated peroxide of iron, and less malleable than meteoric iron.

II. Native iron occurring in a lode in mica-slate, near Canaan, Connecticut } Shephard.

Metallic iron is a constituent of platinum ore, sometimes to the extent of 90·91 per cent.

Hausmann [§] and Karsten [‖] mention many instances of the occurrence of metallic iron in sedimentary rocks, under circumstances which indicate its origin by reduction of iron compounds by organic substance.

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[*] n. Jahrb. für Mineral. etc., 1851, p. 57.

[†] Beiträge. iv, 102.

[‡] Germar.—Taschenb. für Mineral. xv, 925.

[§] Handb. der Mineralogie i, 38.

[‖] Handb. der Eisenhüttenkunde ii., 12.—Bornemann—Poggend. Annal. lxxxviii, 145.

V.—PRESENCE OF METALS IN THE WATER OF SPRINGS, ETC.

It is well known even the most ferruginous spring water contains but very little carbonate of iron. The other metals that have recently been detected in the water of springs, are again but very minute fractions of the iron present, and hence they can be recognized only when large quantities of the water are evaporated, or when the natural deposits from the water are examined.

Schafhäutl* first pointed out, in 1840, the presence of arsenic in iron ore, and the frequent presence of this metal, as well as antimony and tin, in iron. Walchner† showed again, in 1844, that many iron ores contain traces of arsenic and copper, and that these metals are associated with the iron in soils, clay, and marl. Subsequently he found these metals associated in the ochre deposits of springs, and antimony in the ochre at Wiesbaden.

The metals existing in the water of springs, and in their deposits certainly originate from the rocks traversed by the water, whether they are situated near the surface, or at considerable depths. In the deposits from spring water, silica and other nonmetallic substances preponderate largely over the metallic compounds, excepting oxide of iron, and this is also the case in metalliferous lodes, excepting iron ore lodes, with which these ochre deposits present the greatest analogy.

W.—STRUCTURAL CHARACTERS OF LODES.

The succession of the minerals constituting lodes is apparent either in the super-position of layers entirely filling the space between the adjoining rocks, or in the relative position of crystalline minerals in drusy cavities. In the Freiberg district the older lodes do not present the banded structure; therefore the successive production of minerals can be recognised only in the sporadic druses, and the minerals they contain are for the most part different from those constituting the lodes themselves, being either of more recent date, or pseudomorphs. In this district the banded structure appears more distinctly in proportion as the lodes are of more recent date.‡

The individual layers in a lode always extend over both sides of the fissure, and consequently they appear in pairs, corresponding to the saalbands, crystallized towards the central line of the fissure. This fact shows, that the water flowing down both sides of the fissures was of the same character as regards the substances held in solution. The accompanying drawing represents a fragment of a lode traversing gneiss. The recognizable minerals are:—*a*, blende; *b*, quartz; *c*, fluor-spar; *d*, a thin layer of detached crystals and particles of blende; *e*, irregular-curved crusts of heavy-spar; *f*, a thin layer of white iron pyrites; *g*, heavy-spar; *h*, fluor-spar; *i*, white iron pyrites; *k*, white calc-spar; *l*, pale yellow calc-spar, forming small druses at some parts of the middle of the lode.

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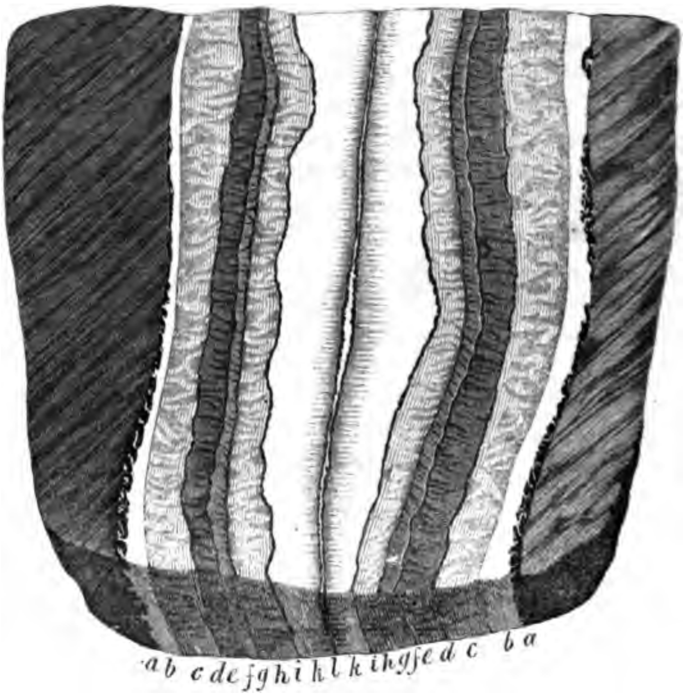
* Journ. für prakt. Chemie, xxi, 129.

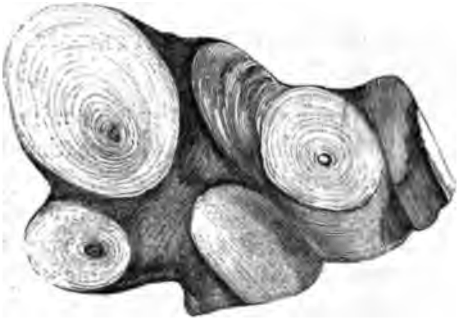
† Amtlicher Bericht über die Versamlung deutscher Naturforscher.

‡ B. Cotta.—Gangstudien ii., 219.

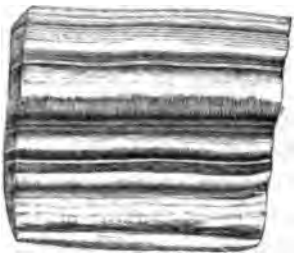

a b c d e f g h i k l k i h g f e d c b a

The perfect identity of these minerals with those that are known to be deposited from water, removes all doubt as to their being produced from water flowing slowly down the sides of the fissure in which they occur. This identity will be apparent from the accompanying drawings, representing a section of the incrustation upon faggots used in salt-works, and a section of the deposit from the Carlsbad water. In the former the deposition has taken place from the centre outwards, while in the lode it has taken place in the opposite direction. Drusy cavities in rocks also present minerals that either resemble those in lodes, or are stalactitic, and in some instances the apertures of infiltration are still recognizable.

1



2



The structural characters of lodes differ essentially from those of rock-veins, or dykes, in which the super-position of the minerals in bands is never presented. By some it may be thought that this is owing to the eruptive igneous origin of the latter; but it has already been shown that this view is inconsistent with the crystalline character of the minerals constituting such veins.

Mechanical deposits of materials originating from the adjoining rocks are not unfrequently met with in lodes. Sometimes masses of such fragments are found covered concentrically with crystalline minerals. Sometimes angular or rounded fragments of the adjoining rocks are jammed close together in large quantities, and without any cementing material. The rounded fragments are covered with a crust of decomposed rock, showing that their spherical form results chiefly from the decomposition taking place to a greater extent at the edges and corners of the fragments, and less from attrition of the masses of rock. When the decomposition of these fragments has been complete, the product sometimes presents the structure of the original rock; sometimes it is washed away by surface water, and deposited in a pulverulent state. Such deposits in lodes are sometimes of very considerable magnitude. The lodes where such loose masses occur, have been subjected to frequent dislocations, as is shown by the polished surfaces, and the thin bright laminæ into which the deposited material may be detached. Sometimes such mechanical deposits occur without any crystalline minerals. They are, also, met with at apertures between strata, originating from the decomposition of the rock by water flowing between the beds. In the Saxon Erzgebirge there are faults in some of the lodes at these points, and at the same time the lodes are richer there.

X.—CONCLUSIONS FROM THE ASSOCIATION OF DIFFERENT CONSTITUENTS OF LODES.

When metalliferous minerals occur indiscriminately mixed together with other minerals, as in the first-named lode formation,* the former as well as the latter have originated from sedimentary rocks by crystallization from water; for the above-mentioned occurrence of sulphuretted cupreous minerals and galena,† shows that deposits of ore are not unfrequently situated in sedimentary rocks. The crystallization of the metalliferous minerals was in this case subsequent to that of the other minerals—augite, vesuvian, and garnet.

So, likewise, in the crystalline rocks, in lodes, and the drusy cavities of the second lode formation, the crystallization of the felspar preceded that of the anatase, rutile, etc. The order in which the material for these minerals appears to have been provided, presents an unmistakable analogy with the formation of crystalline rocks from amorphous masses generally. Thus, for instance, as the quartz in granite is of later origin as a product of decomposed silicates, titanic acid may also have originated from the decomposition of titanates. The association of titanic acid with quartz, sometimes of simultaneous, and sometimes of prior or subsequent origin, indicates that both are co-ordinate products of decomposition. Since the titanic acid in drusy cavities was undoubtedly introduced by the action of water, there is no difficulty in ascribing the same kind of origin to the titanic acid occurring in crystalline rocks.

If the elimination of quartz and oxide of tin were co-ordinate processes, the deposition of the former preceded that of the latter mineral in the third lode of formation. As silicate of tin occurs native, it is possible that the oxide of tin is a product of the decomposition of that silicate; but so long as silicate of tin is not observed in the rocks containing the lodes, this can only be regarded as a possibility.

* See ante, p. 438.

† Ibid, p. 436.

‡ See ante, p. 519.

In the fourth lode formation quartz is always the initial member of the series, and it preponderates more largely than in any other lode formation. It is generally mixed irregularly with iron pyrites, arsenical pyrites, galena, and blende, and there is rarely any banded structure. The lodes belonging to this formation very often contain small angular fragments of the adjoining rock, sometimes filling the entire lode. These fragments, with the slaty structure crossing in all directions, are generally imbedded in quartz, which not unfrequently penetrates them throughout. This quartz is firmly attached both to the fragments and to the adjoining rock, which is highly carbonaceous near the lodes. Where this rock consists of greenstone, it frequently presents alteration into a soft kaolin or steatitic mass, and sometimes a compact serpentine resembling gabbro.

In the lode formations V to IX, XI and XIV, quartz is by far the most frequently the initial member; silica was, therefore, the first product, and, consequently, felspar or a felspathic mass was the constituent of the adjoining rocks that first underwent decomposition. When, as is so often the case, the metalliferous minerals in lodes are imbedded in quartz, nothing can be more certain than that they have the same origin as the quartz, that they result from the decomposition of silicates.* Oxide of copper occurs in green felspar,† and it may be that other kinds of felspar contain minute quantities of other metallic oxides. Daub found in the centre of a twin crystal of orthoclase from a lode, a substance similar to brown spar, with a few distinct patches of galena; and in the undecomposed outer portion of a twin crystal from porphyry, a nucleus of galena.‡

When quartz is followed by metalliferous minerals, the silicates from which it originated either did not contain metals, or they were brought into the lodes at a subsequent period. There is no doubt that the ores of iron and manganese have originated from the decomposition of silicates of these metals, for they always occur in rocks that are rich in such silicates. Weissenbach states, that near Johanngeorgenstadt, the hematite lodes generally follow the junction of the granite and mica schist, and they extend into the latter only as ferruginous clay and slate. There is no doubt that in this instance the iron ores originated from the mica schist that is so rich in silicates of iron,§ and which is somewhat decomposed near the lodes. But the products of this decomposition are found separately in the lodes, the quartz being the first, and the brown hematite the second member. This separation may be easily accounted for, when it is remembered that the small amount of carbonic acid contained in water would be in the first instance consumed in effecting the decomposition of the silicates. The water thus deprived of its carbonic acid could not dissolve the carbonate of iron that had been produced, but it could exercise the same solvent action upon the silica that had been eliminated, as water containing carbonic acid. Consequently, it removed the silica, and deposited it in the lode fissures. When the decomposition of the silicates of iron was so far advanced that carbonic acid was no longer consumed in this way, the carbonate of iron would be dissolved and carried into the lode, where, according as there was or was not access of atmospheric air, it would be deposited as hydrated peroxide or as carbonate of iron. This process is, however, susceptible of manifold modification. If the water by which the decomposition of the silicates was effected contained, besides carbonic acid, oxygen, this gas would act during the decomposition upon the oxide of iron, so as to prevent the production of carbonate of iron. But if it contained organic substance, the persilicate of iron would be reduced to protosilicate, and the carbonic acid produced simultaneously, would facilitate the solution of carbonate of iron. When these conditions preponderate, it is quite conceivable that iron and manganese minerals will more frequently constitute the initial member than quartz, as in the tenth lode formation. Although it is not easy to perceive why the solution and transfer of the silica should be entirely suppressed, or why in some instances it should not have taken place until after the solution and transfer of the oxide of iron, it is certain that this has been the case, and the explanation of the fact has still to be furnished.

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* See ante, p. 435.

† Ibid, p. 446.

‡ N. Jahrb. für Mineral., etc., 1851, p. 8.

§ See ante, p. 342.

In the fourth lode formation the metalliferous minerals, and especially the richer silver minerals, are almost always finely disseminated through the quartz, and sometimes in such minute particles that they only give a grey colour to the quartz. The red silver ore, also, occurs as a film, or crystallized in drusy cavities, more rarely as very delicate laminæ imbedded in clear transparent quartz crystals. The spathic minerals are, also, met with partially in drusy cavities. Consequently, these minerals were deposited together with the quartz, and probably originated from the decomposition of silicates.

Since it happens that in the greater number of lodes in which quartz is the initial member, it is followed directly by the metallic sulphides, the opinion that these minerals have a common origin is also admissible in that case; for, just in the same way that the iron minerals originating from the decomposition of ferruginous silicates were deposited after the quartz, it is possible that other metallic compounds eliminated by the decomposition of silicates were deposited after the silica originating from the same source.

Since it is rarely that metalliferous minerals in lodes are in direct contact with the adjoining rock, it is possible that the conditions under which the elimination of metallic compounds took place first, in the decomposition of silicates, rarely prevailed; but too little is known of this subject to justify a decided opinion.

In the sixth lode formation carbonates are first met with, and a careful comparative study of the varied connection between the several members of these lodes, and of the constituents of the adjoining rocks, would, probably, lead to a better knowledge of their origin. Where carbonates occur in the lodes, the decomposition of the silicates, and the elimination of metallic compounds, may be referred to carbonic acid. It is remarkable that calc-spar, one of the most soluble carbonates, always appears to be of more recent origin than the metalliferous minerals. But when it is remembered that this carbonate is, most of all, liable to alteration, and that, in this lode formation, pseudomorphic changes have not been unfrequent, it will appear quite possible that this calc-spar may be the product of some subsequent alteration.

The assumed connection between the production of carbonates and the elimination of metallic compounds, is consistent with the association of carbonates, such as rose-spar and bitter-spar, with galena and blende; for, if the metals as well as the earths were eliminated as carbonates, and if these were at the same time carried away by water, and deposited in fissures, mixtures of earthy and metallic carbonates would have been produced. By the subsequent conversion of the latter into sulphides, these minerals would remain associated with the earthy carbonates. The above-mentioned* frequent alternation of spathic carbonate of iron with blende and galena, is only an instance of a mixture consisting of substances, in the formation of which the deposition of one constituent lasted for a greater or less period without admixture of the other.

Some geologists still seem to consider that the metalliferous and earthy constituents of rocks have originated in different ways. When the two are separated sharply, it is very difficult to perceive how two independent processes—the infiltration of the earthy constituents from the adjoining rocks, and the introduction of the metallic constituents from the interior of the earth—should alternate with such distinctness. When the earthy and metallic constituents are blended together, their different origin might be more easily conceived; but as the perfect absence of one or other lode-member would indicate the perfect cessation of one or other process of formation, there would still be the same difficulty in accounting for the mutual exclusion of two independent processes. Therefore, the above view, by which it is sought to establish the eruptive origin of the metallic constituents of lodes, appears to be quite inconsistent with the phenomena presented by metalliferous veins.

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* See ante, p. 439.

Although it is not without difficulty to account for the sharp separation of various lode-members, by supposing them to be deposits from water, these phenomena may be connected with known chemical processes. In washing precipitates, it not unfrequently happens that the liquid passes through clear for some time, and, afterwards, becomes turbid. This is owing to the alteration of the liquid, since water containing salts in solution may not dissolve the precipitate, although pure water would do so. In like manner the solvent action of the water penetrating rocks may vary according to the substances it contains in solution, so that, for some time, one mineral would be removed, and at another time other minerals.

With regard to the occurrence of fluor-spar as a lode-member, especially in lodes belonging to the twelfth formation, it may be remarked that fluorine is very generally distributed,* occurring in many minerals, and often in water; and that although it may not be combined with calcium, its other compounds are very readily converted into fluoride of calcium.†

In minerals, the amount of fluorine is sometimes only 0·16 per cent., and in rocks it is not estimable. At the same time fluoride of calcium is soluble in 26,923 times its weight of water. Comparing these facts with the very enormous masses of fluor-spar occurring in lodes, it becomes evident that minimum quantities in rocks may become maximum quantities in lodes. If the minerals containing mere traces of fluorine also contained metals, amounting only to fractions of the quantity of fluorine, and if they were transferred to the lodes, together with the fluorine, it would be intelligible that the metalliferous minerals constitute only a fraction of the fluor-spar, associated with them in lodes. Pyrochlore contains, together with fluorine, oxide of uranium 1·6 per cent. lead, and 0·7 tin; œschynite contains 0·5 per cent. tin. Fluoride of tin is readily soluble, and fluoride of lead is to some extent soluble; so that it is not improbable that the galena occurring abundantly in the fluor-spar of this lode formation, was brought into the lode as fluoride of lead, which was afterwards decomposed.

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* English edition, ii, 1.

† Ibid.

It has already been attempted * to account for the production of heavy-spar in lodes.

In the lodes belonging to the twelfth formation, near Freiberg, irregular quartz fragments of unequal size, are intimately mixed with the heavy-spar. Bournonite, copper pyrites, iron pyrites, sulphide of antimony and silver, are imbedded partially in quartz, and partially in heavy-spar, and consequently were deposited at the same time as those minerals. If heavy-spar was deposited as sulphide of barium, the production of the above sulphides from oxygen compounds would be intelligible. But metallic arsenic occurs, both upon and imbedded in, the heavy-spar. Calc-spar is always the most recent mineral in the lodes of this formation, and the richer silver ores are generally associated with it. The Drei-Prinzen-spath lode at Freiberg, often presents a very marked superposition of its constituent minerals, bands of quartz, fluor-spar, heavy-spar, alternating repeatedly with thin layers of white iron pyrites, and magnetic pyrites. The Ludwig-spath lode is sometimes entirely filled with decomposed gneiss and clay. The adjoining rock of the lode is generally bleached and decomposed to a considerable distance.

The lodes belonging to the ninth formation, in the neighbourhood of Mobendorf (Erzgebirge), are remarkable from appearing as irregular veins, or as a network of very irregular masses in the gneiss, sometimes quite unconnected, and rarely more than two inches thick. They generally contain sulphide of antimony, berthierite, bournonite, etc. Sometimes there are small nests in the midst of the gneiss, without any vein joining them.†

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* English edition, i, 441.

† H. Müller.—Op. cit.

Y.—RELATIONS BETWEEN LODES AND THE ADJOINING ROCKS.

The observations made by Werner, Freisleben, v. Charpentier, J. Ch. L. Schmidt, and others, have contributed much to our knowledge of this subject; but in the present instance, reference will be made only to the views that have been more recently put forward as to the origin of metalliferous veins.

Daubree[†] considers that tin ore, titanic acid, oxide of iron, and to some extent, quartz also, have been produced by the reaction of water vapour with fluorides and chlorides, assuming that at remote periods fumaroles containing hydrofluoric acid existed. Elie de Beaumont[‡] endeavoured to refer the production of lodes partly to volcanic exhalations of metallic substances, and partly to mineral springs. H. v. Dechen[§] pointed out the peculiarities in the association of a large number of minerals in lodes, the relations to each other, of certain of those minerals which appear to be constantly associated, and their relations to the substances known to exist in volcanic exhalations, and to those brought to the surface by mineral springs. Gruner,[‖] Delanoue,[¶] and Thirria,[**] have also put forward their views on this subject.

The artificial production by Durocher[††] and Senarmont[‡‡] of certain metalliferous minerals, partly in a crystallized state, similar to that of native ores, is interesting chiefly from a mere chemical point of view, rather than of any geological significance. Durocher infers, from the comparison of sulphides obtained at high temperatures, with those obtained by Senarmont in the wet way, that native minerals have often been produced in different ways. The production of sulphides by the reaction of sulphuretted hydrogen with metallic chlorides at a red heat, cannot however be admitted to have taken place in lodes.

As a general consequence of the relations between the matrices of lodes, the rocks adjoining them, and their condition, as well as those between different lodes, it may be inferred that all the substances contained in lodes have been derived from the adjoining rocks. Werner was of opinion that the more recent products in lodes occur for the most part only at the upper parts. In some instances this is the case,* but v. Weissenbach† also observed the opposite case, for instance, at Freiberg, heavy-spar and fluor-spar occur in many lodes only at the deeper parts, and in some galena lodes, the spathic minerals occur only at the deeper parts.‡ There is, however, a frequent difference between the contents of lodes at different depths; thus the richness of the iron ore lodes at Eibenstock, diminishes with the depth; § and this is also the case with the gold mines of Chili.

[†] Comptes rendus., xxix, 227.

[‡] Bullet. géol. (2), iv, 1249.

[§] Verhandl. d. Naturhist. Vereines d. pr. Rheinlande, etc., Jahrg. VII., 161.

[‖] Ueber die Bildungsweise der manganerze in den Pyrenäen, etc.

[¶] Ueber die Bildung der Zink, Blei, Eisen und Manganerze auf unregelmasigen Lagerstätten.

[**] Ueber die Analogieen in der Bildungsweise der Bohnerz-Ablagerungen, etc.—Archiv. für Mineral., etc., xxv, 510.

[††] Comptes rendus, xxviii, 607, and xxxii, 823.

[‡‡] Ann. de chim. et de phys. (3), xxx, 129, and xxxii, 129.

These facts show decisively the connection between the nature of the rocks and that of the lodes traversing them. The removal of constituents from a rock is always preceded by its decomposition, and is facilitated by the advance of the decomposition. Wherever quartz exists in lodes, the adjoining rock is more or less converted into kaolin, so that we find in the one place, what is deficient in the other; and when it is found that the abundance of ore in a lode is proportionate to the extent of decomposition of the adjoining rock, this circumstance can only be regarded as a consequence of such decomposition. It is totally inconsistent to refer phenomena so essentially opposite as the silicification and the decomposition of rocks, to one and the same cause, viz., the protrusion of melted masses or sublimation. The action of heat would not cause either the conversion of felspar into kaolin or the silicification of rocks; the former change requires water, which is always present in the kaolin; the latter requires a solution of silica.

The fact that the thickness as well as the richness of lodes decreases where they pass from one rock to another, shows that not only the composition but also the mechanical texture of the adjoining rock influences the formation of the lode, by determining the width of the fissure. The more a rock is rent like serpentine, the less likelihood is there of wide fissures being formed in it. When it is remembered that the non-metallic minerals are generally deposited before the metallic ores, it will be evident that narrow fissures might be filled up with the former before the deposition of the latter commenced. Hence we find narrow fissures in clay-slate so frequently filled with quartz, while the wider fissures near them also contain metalliferous ores.

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* Kühn.—Handbuch der Geognosie II., sec. 697.

† Abbildungen merkwürdiger Gangverhältnisse, p. 37.

‡ Oppe.—Op. cit., p. 191.

§ Op. cit. p. 13.

The connection between the abundance of metalliferous ores in lodes, and the presence of certain minerals in the adjoining rocks, may be due to different causes. Whether, in the production of those minerals, the metallic compounds existing in the rocks entered into their composition or not, there would be a concentration of the metals, either in the minerals produced, or in the matrix of the rocks, so that, in both cases, the extraction and removal of the metals into lodes by the action of water would be facilitated. The concentration of iron is apparent in the production of highly ferruginous minerals—augite, hornblende, etc.; and the decomposition of these minerals would yield abundant material for the production of iron ore lodes. It is true, the concentration of other metals in like manner cannot be supposed to take place to an equal extent, because no other metal but iron is found so abundantly in minerals.

The deposition of tin ore in lodes appears to be especially connected with the presence of tourmaline in the adjoining rock.* Analysis does not render it probable that tin ever enters into the composition of this mineral. But the reverse case, that there is a concentration of the tin ore disseminated through a rock where tourmaline is produced, has been observed; for, since the tourmaline of Eibenstock is one of the most ferruginous varieties, it has appropriated greater part of the iron in the rock, and thus relatively increased the amount of tin ore. If tourmaline were not produced, water would extract from the rock much more peroxide of iron than oxide of tin, and iron ore lodes would then be produced.

In attempting to offer an explanation of the phenomena of increase and decrease of ores observed at the junction and intersection of lodes, it is necessary, in the first place, to consider the pseudomorphic changes which Breithaupt's investigations have shown to obtain in the case of the Saxon lodes. Oppe has also pointed out that, in the iron ore lodes at Eibenstock, there are numerous pseudomorphs after calc-spar, brown-spar, heavy-spar, and fluor-spar, anhydrite, iron pyrites, pyromorphite, and quartz, of which minerals, however, there are, at most, but mere traces still remaining. The carbonate of lime has been displaced by red and brown hematite, silicate of iron, quartz, and horn-stone; the heavy-spar, anhydrite, and fluor-spar, by red hematite and quartz;

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* See ante, p. 518.

the quartz and pyromorphite by red hematite; or, at least, there are impressions of the crystals of the substances removed. In this instance, therefore, the lodes have become richer in the course of time.

Such changes taking place in lodes, presuppose the access of water to the lodes; and wherever there is a junction or intersection of lodes, there will be an admixture of the water traversing the different lodes, and, consequently the greatest opportunity for displacement to take place. If the non-metallic minerals in the lodes are displaced by metalliferous minerals, the lodes would be enriched, and in the contrary case impoverished.

The deposition of ores in lodes traversing crystalline rocks, and the production of the latter from amorphous rocks by metamorphism, may, in some instances, be co-ordinate processes, for if the latter rocks contain substances which do not enter into the composition of felspar, mica, and the other minerals constituting crystalline rocks, they would be eliminated during the production of these minerals, and carried into lodes by water. This conclusion is the more probable from the dissimilarity between the minerals in lodes and those constituting crystalline rocks. But in making this comparison we must consider not only the minerals now met with in lodes, but also those whose former existence is indicated only by pseudomorphs. The whole of the above-mentioned minerals, formerly existing in the lodes at Eibenstock, are foreign to granite, or occur in its constituents only in very minute proportions; consequently their presence could only have been a hindrance to the production of granite. The pseudomorphs after calc-spar are most frequent in these lodes, so that lime was removed in larger quantity from the adjoining rocks, and this corresponds with the fact that lime does not occur at all in mica, and only to a small extent in felspar. In like manner the varieties of mica occurring in granite generally contain but little iron, and felspar also contains but a small proportion of iron.

If all the fissures in a sedimentary rock had become filled with lode substances, and if no displacement went on subsequently, the removal of foreign constituents from the mass of the rock could take place only along the planes of stratification. If, moreover, this removal were very limited, and yet a necessary condition of the production of a crystalline rock, very long periods of time might elapse before the sedimentary rock acquired a crystalline condition. It may be owing to this, or some such circumstance, that the clay-slate rocks, in which such lodes occur, have not yet become crystalline, or, at least, only imperfectly so.

Z.—PRODUCTION OF ORES.

The deposition of ores in lodes is essentially dependent upon the conversion of soluble metallic compounds, conveyed into them by water, into insoluble or sparingly soluble compounds. The impregnation of water with various substances derived from the atmosphere and the rocks which it permeates, affects in a variety of ways its solvent action upon other substances, and also determines the action exercised upon metallic compounds; and since it is precisely the least soluble compounds of metals that are met with as ores, the general chemical fact that the least soluble compounds are produced when different solutions are mixed together, has obtained in lodes as elsewhere. Nothing could furnish stronger evidence of the production of ores in the wet way, than this simple fact. The soluble metallic compounds that gave access to lodes, would not give rise to the production of ores unless they came in contact with the substances with which they give rise to the production of the less soluble compounds. The most volatile of the metallic compounds, the fluorides and chlorides, would not remain in the lodes even if it were possible for them to be introduced by sublimation, because with the exception of the subchloride of mercury they are all readily soluble in water. There is not indeed a single known phenomena presented by lodes which would show that the chemical affinities called into play by the action of heat have obtained in lodes. We find sulphides of lead, antimony, and mercury associated with enormous masses of carbonates of iron and lime, though iron and lime decompose those sulphides by the aid of heat. We find quartz associated with iron ores, while in metallurgical operations it is employed for separating the iron as a readily fusible silicate, etc.

It has already been shown in several places what are the solvents by which the metallic compounds hitherto regarded as insoluble, are transferred from rocks into the lodes traversing them, and there can be no question that the progress of investigation will make known numerous other cases of the same kind of action.

The silicates of zinc, copper, nickel, and silver are so soluble in pure water, that their solubility may be determined. Silicate of lead is, however, as sparingly soluble in pure water as sulphide of lead, but it dissolves in sensible amount in water containing alkaline silicates, or carbonates. Therefore if the above silicates exist in rocks, they may be transferred to the lodes by water, and since these silicates, and probably all metallic silicates are decomposed by carbonic acid, this alteration may take place both in the lodes and in the adjoining rocks. In the latter case the carbonates would be carried by water, together with the silicate eliminated, into the lodes, inasmuch as the metallic carbonates are much more soluble than the corresponding silicates. In like manner carbonic acid would decompose the silicates deposited in lodes, with production of carbonates and silica, so that the production of carbonates in this way in lodes is readily intelligible. Iron-spar has certainly always been produced in this way; carbonate of lead, malachite, blue carbonate of copper, and other carbonates are, however, mostly products of the decomposition of sulphides previously existing in the lodes.

The silicates of zinc and lead suspended in water are decomposed by sulphuretted hydrogen, with production of sulphides and elimination of silica. The silicates of copper, nickel, and silver are decomposed in like manner; but the resulting sulphides dissolve in the sulphuretted hydrogen water, and are not deposited until the sulphuretted hydrogen is disengaged. If, therefore, these silicates exist in rocks, and come in contact with sulphuretted hydrogen water, the dissolved sulphides would be carried into the lodes and there deposited.

The carbonates of lead, copper, and silver, as well, even, as those of metals that are not precipitated by sulphuretted hydrogen from solutions of their other salts, are also decomposed by sulphuretted hydrogen. Therefore all these carbonates would be converted into sulphides by contact with sulphuretted hydrogen in lodes.

The known occurrence of sulphuretted hydrogen in the water of some springs, its production by decomposition of sulphates by means of organic substances, render it unnecessary to inquire after the source of this agent of ore production. If quantities of sulphuretted hydrogen, such as gave rise to the enormous masses of sulphur in Sicily, had been decomposed by metallic compounds, instead of oxygen, masses of sulphides would have been produced, equal in extent to the largest known lodes. The decomposition of fuci also gives rise to large quantities of sulphuretted hydrogen, and hence we find metallic sulphides in the sedimentary rocks deposited from the sea.

In the lodes traversing sedimentary rocks, the conditions for the generation of sulphuretted hydrogen would be extremely favourable, in consequence of the decomposition of organic remains. Even were there but mere traces of this gas, it would act in the same manner as traces of it in the atmosphere are known to do, more especially since there is but a very limited communication between lodes and the atmosphere. In crystalline rocks, also, where the richest ores generally occur, the conditions for generation of sulphuretted hydrogen exist. The occurrence of sulphuretted springs in the granitic district of the Pyrenees is evidence of the presence of this gas in crystalline rocks.

The production of sulphides presupposes the existence of sulphates, and the elimination of sulphur from sulphates, either in combination with hydrogen, or with metals of the alkalies, or alkaline earths, presupposes the existence of organic life, since that effect would be produced only by carbonaceous substances. The influence of organic substances in the production of sulphides is further shown by the fossil remains consisting of iron pyrites, blende, copper pyrites, variegated copper pyrites, sulphide of copper, and cinnabar.

Since sulphate of lime is, next to carbonate of lime, the most abundant in the water of rivers, this must also be generally the case with the water permeating rocks. Consequently the contact of sulphates and organic substances in rocks must be regarded as of frequent occurrence, not only at the present time, but ever since the existence of organic life.

The production of carbonate of iron in rocks containing only silicates of peroxide of iron, and its removal by water, presupposes the reduction of peroxide of iron to protoxide, by organic substance. If sulphates were at the same time introduced by water, they would also be reduced. But, since the amount of iron compounds in most sedimentary rocks preponderates over the sulphates introduced into them by water, and since, moreover, the carbonic acid is both constantly supplied by water and produced by processes of reduction, the production of carbonate of iron, under these circumstances, would far exceed that of sulphides, and only small quantities of iron pyrites would be produced. Water would then carry the carbonate of iron into the lodes, and the sulphides, being insoluble, would remain in the rock.

The occurrence of large lodes of iron-spar show that the processes of alteration going on in rocks do take this direction. It is also by no means unfrequent, that iron-spar contains small quantities of iron pyrites, the production of which, in this case, cannot be otherwise explained than as the effect of sulphuretted hydrogen exercised during the deposition of the carbonate of iron.

This also applies to the association of other sulphides with iron-spar. Among these, copper pyrites is most frequent, even more so than iron pyrites. The circumstance that sulphide of iron, which is a constituent of copper pyrites, is the most frequently associated with iron-spar, appears deserving of notice, and indicates the similarity of origin of the sulphides and carbonate of iron. The carbonated water containing sulphates and organic substance, abstracted from the rocks protoxides of iron and copper, and carried them into the lodes as carbonates, of which the carbonate of iron would be deposited first, in consequence of the disengagement of carbonic acid from the water; and the carbonate of copper subsequently, because its amount would be far less than that of carbonate of iron. At a subsequent period, the sulphates being decomposed by organic substance, the soluble sulphides would convert the carbonates of copper and iron into copper pyrites and iron pyrites, while the metals of the soluble sulphides would be removed as carbonates. If the soluble sulphides were insufficient to convert the whole of the carbonate of copper into sulphide, the remainder would appear as malachite, or blue carbonate, in the lodes.

Besides these two sulphides, iron-spar is sometimes accompanied by galena, blende, mispickel, grey copper ore, and sulphide of antimony. The first two would originate in the same manner as the copper pyrites, but this would not be the case as regards the other sulphides whose metals have no corresponding carbonates.

Those metals that occur as arsenides, also occur as arsenates; but it is remarkable that although there are several arsenates of copper, arsenide of copper occurs only in the rare mineral condurrite. The arsenates of copper probably originate from the very frequently occurring arsenical grey copper ore by oxidation. There is not any simple arsenide of lead, and consequently no arsenate of lead. Moreover, compound arsenides rarely contain lead, and this corresponds with the equally rare occurrence of arsenic acid in lead ores.

The oxidation of arsenides is a well-known fact, and the reproduction of arsenical pyrites from arsenates and sulphates by reaction with organic substance is very probable. Hence there seems to be an analogy between sulphides and arsenides, as there is between sulphates and arsenates, and this is the more evident from the fact that solutions of many metallic salts are decomposed

by arsenietted hydrogen. It is worth pointing out that cop
salts are especially susceptible of this decomposition, because
circumstance corresponds with the very frequent occurrence
arsenates of copper. Since arsenide of iron occurs native, both
itself and in combination with arsenides of nickel and cobalt,[*]
since it evolves arsenietted hydrogen by solution in dilute hyd
chloric or sulphuric acids, there is much probability that this
may be generated in lodes by the action of carbonic acid
arsenide of iron. However it is still uncertain whether
analogy between arsenic and sulphur compounds extends so
that it may be assumed that arsenates are the source from whi
arsenides are produced.

There is likewise a great similarity between arsenides, antim
nides, and tellurides, and some metallic salts are decomposed
the corresponding hydrogen compounds, but beyond this nothi
is known.

The above considerations relating to the production of
various classes of ores, show that what is known with regard
this subject is but a fraction of what has to be learnt; and it
from more extended knowledge of the mineralogical and chemi
characters of ores, of the pseudomorphic processes they under
the detection of minute traces of substances that give rise to
production and alteration of minerals, as well as the observation
the phenomena of association presented by ores, with each ot
and with the minerals accompanying them, that we may expect
attain to a more complete insight into their origin.

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[*] See ante, p. 477.

FINIS.

INDEX.

A.

Actinote, ii. 340.
Adelforsite, ii. 147.
Adriatic, deposits in the, i. 138.
Adular, ii. 158.
„ analyses of, ii. 167.
Albite, ii. 191.
„ analyses of, ii. 167, 192, 195.
„ associated with epidote, ii. 192.
„ „ orthoclase, ii. 165.
Alteration indicated by increase or decrease in the amounts of constituents, i. 49.
„ of amorphous minerals, i. 50.
„ of clay slate, iii. 318.
„ of hornblende rocks, iii. 302.
„ of minerals, i. 1, ii. 58, iii. 1.
„ „ preservation and obliteration of form in, i. 26.
„ at St. Gothard, ii. 167.
„ pseudomorphic, i. 33.
„ „ generally commences with hydration, iii. 363.
„ of rocks at their line of contact, iii, 82.
„ of silica in clay slate, iii. 328.
„ by substances in water, i. 24.
„ of trachytic rocks, iii. 407.
„ by water permeating rocks, i. 36.
„ of zeolites, i. 157.
Alteration-pseudomorphs, i, 18.
Alum-slate, iii. 134.
Alumina, silicate of, ii. 125.
„ an extraction from minerals, ii. 65, 146.
„ reaction with fluoride of potassium, i. 14.
Aluminates, iii. 449.
Amazon-stone, ii. 159.
Ammonia in the atmosphere, i. 210.
„ carbonate of, in water, i. 52.
Amphodelite, ii. 215.
Amsterdam, deposits under, iii. 40.
Analcime, alteration of, ii. 140, 142.
Analcime, analyses of altered, ii. 143.
Analyses of air in sea-water, i. 114.
„ of basalt, iii. 247.
„ of Carrara marble, iii. 141.
„ of clay, i. 130, iii. 139.
„ of dolerite, iii. 233.
„ of ferruginous deposits, i. 159.
„ of hornblende rocks, iii. 294.
„ of lake water, i. 94.
„ of melaphyr, iii. 220, 230.
„ of nepheline rock, iii. 260.
„ of sea-water, i. 89-98.
„ of substance suspended in Rhine water, i. 123.
„ of syenite, iii. 286.
Anatase, iii. 519.
Andalusite, ii. 266.
„ oxygen quotient of, ii. 269.
„ identical with chiastolite, ii. 267.
„ conversion into mica, ii. 27.
„ „ „ cyanite, ii. 270.
„ „ „ steatite, ii. 272.
„ rocks in which it occurs, ii. 266.
„ not liable to alteration by exposure to the atmosphere, ii. 273.
Andesite, iii. 393.
Anhydrite, action of water on, i. 428.
Anorthite, ii. 212.
Anthracite, i. 246.
Antimonates, iii. 490.
Antimonides, iii. 477.
Antimony, iii. 538.
„ oxide of, iii. 520.
„ sulphide of, iii. 470.
Antophyllite, ii. 340.
„ solution by water, i. 31.
Apatite, ii. 25.
„ in granite, ii. 31.
Aphanite, iii. 411.
Apophyllite, ii. 152.
„ solubility in water, i. 60.
Appalachian coal measures, i. 299.
Arragonite, conversion of, into calc-spar, iii. 153.
Arsenates, iii. 491.

Arsenides, iii. 477.
„ origin of, iii. 556.
Arsenic, native, iii. 538.
„ oxide, iii. 521.
„ sulphides, iii. 470.
Asbestos, analyses of, ii. 318.
„ occurrence of, ii. 341.
„ pseudomorphous, ii. 318.
Atlantic, water of, i. 100.
Augite, ii. 304.
„ conversion into hornblende, ii. 314.
„ alteration of, ii. 314.
„ conversion into asbestos, ii. 320.
„ „ „ steatite, ii. 322.
„ „ „ serpentine, ii. 321.
„ formed in the wet way, ii. 307.
„ possible igneous origin of, ii. 307.
„ relation to hornblende and asbestos, ii. 321.
Augitic rocks, iii. 203.

B.

Baryta-harmotome, ii. 152.
Baryta, sulphate of, i.
„ „ decomposition of, i. 30.
Basalt, iii. 238.
„ contact of other rocks with, iii. 74.
Bismuth, iii. 537.
„ carbonate of, iii. 511.
„ oxide of, iii. 533.
„ silicate of, iii. 447.
„ sulphide of, iii. 469.
Bitter-spar, pseudomorphous, iii. 165.
Black-earth of Russia, i. 135.
Blende, iii. 456.
„ in fossil remains, i. 48.
„ production of, i. 15.
Bog-iron ore, i. 166.
Brine springs of Neusalzwerk, i. 146.
Brochantite, iii. 515.
Bromides, iii. 516.
Bronzite, conversion into serpentine, ii. 334.
Bytownite, ii. 215.

C.

Cadmium, sulphide of, iii. 469.
Calamine, iii. 508.
„ deposits of, i. 165.
Calcareous deposits, i. 146.
„ rocks, origin of, i. 125.
„ „ solution of, i. 116.
„ sinter, i. 150.
Caledonite, iii. 515.
Calcium, chloride of, in water, i.
„ „ reaction with sulphide of barium, i. 16.
„ fluoride of, ii. 5.
„ „ solubility of i. 44.
„ „ reaction with, alkaline carbonates, i. 11.
Calc-spar, conversion into bitter-spar, iii. 175.
„ displacement by chlorite, ii. 408.
„ removal from lodes, i. 35, 51.
„ pseudomorphs after, iii. 174.
„ in cavities of dolomite, iii. 196.
Carbonates, ii. 41; iii. 493.
„ alkaline, action upon magnesian salts in water, i. 113.
„ „ reaction with silicate of lime, i. 8.
„ „ action upon rocks, iii. 90.
„ decomposition by silica, i. 6; in river water, i. 82.
„ earthy, ii. 42.
„ metallic, iii. 493.
„ in rocks, i. 9.
„ in water, iii. 173.
„ composition of acid, iii. 170.
Carbonic acid, displacement from water, iii. 5.
„ in water, source of, i. 1.
„ influence on decomposition of rocks, ii. 182.
„ in sea water, i. 116.
„ in meteoric water, i. 52.
Caspian Sea, i. 90.
Cerite, iii. 442.
Chabasite, ii. 152.
Chalcedony, pseudomorphous, ii. 156.
Chemical action, influence of temperature, pressure, and water on, i. 31, 57.
Chesterlite, ii. 163.
Chiastolite, ii. 266.
Chloride of calcium, reaction with sulphide of barium, i. 16.
„ of magnesium, in water, i. 17.
„ „ reactions with sulphides of potassium and barium, i. 15, 16.
„ of sodium, deposition of, i. 111.
„ „ reaction with silicate of potash, i. 12.
Chlorides, alkaline,
„ metallic iii. 515.
„ in river water, i. 82.
„ in sea water, i. 110.
Chlorite, ii. 406.
„ analyses of, ii. 407.
„ associated with garnet, ii. 407.
„ conversion of felspar into, ii. 174.
„ pseudomorphous, i. 407, 408.
„ formation, ii. 415; from felspar

tourmaline, hornblende, and garnet, ii. 173, 263, 290, 346, 408.
Chlorite, decomposition, ii. 415.
„ in melaphyr, iii. 228.
„ mineralogical characters of pseudomorphous, ii. 409.
„ conversion of diorite into, iii. 312.
Chlorite-slate, iii. 352.
Chloritic substance as a petrifying material, ii. 411.
Chromates, iii. 488.
Chromium, oxide of, iii. 520.
„ silicate of, iii. 442.
„ cinnabar, iii. 469.
„ on fossil fish, i. 44.
Clay, analyses of, i. 130, ii. 139.
„ deposits on the Lower Rhine, i. 129.
„ similarity to river mud, i. 123.
Clay-slate, iii. 122.
„ „ micaceous constituent of iii. 350.
„ „ conversion into mica-slate, iii. 348.
„ „ „ granite, iii. 411.
„ „ alteration of, iii. 318.
„ „ comparison with syenite, iii. 326.
Clinkstone, iii. 388.
Cleavage, slaty, iii. 18.
Clinochlore, ii. 407.
Cobalt, carbonate, iii. 511.
„ oxide of, iii. 533.
„ silicate, iii. 447.
„ sulphate, iii. 515.
„ sulphide of, iii. 469.
Conglomerates limestone, iii. 118.
Copper native, iii. 537.
„ carbonates, iii. 509.
„ chloride of, iii. 515.
„ on fossil fish, i. 44.
„ oxide of, iii. 532.
„ pyrites, iii. 458.
„ silicate, iii. 445.
„ grey, iii. 475.
„ sulphate of, iii. 515.
„ „ reaction with bicarbonate of lime, i. 13.
„ sulphide of, iii. 457.
Coquimbite, iii. 514.
Corderite, ii. 274.
„ alteration of, 275, 281.
„ chemical features of its alteration, ii. 281.
„ „ relation to mica, i. 48.
„ conversion into mica, ii. 279.
„ derivatives of, ii. 279.
Covellite, iii. 459.
Criptolite, iii. 514.
Crystallization of melted masses, i. 33.
„ by fusion and solution, ii. 93.
Cyanite, ii.

D.

Danube, suspended substance of i. 131.
Datolite, alteration of, ii. 156.
Dead Sea, i. 92.
Decomposition of basalt, iii. 256.
„ „ basaltic rocks, iii. 262.
„ „ crystalline rocks, iii. 59.
„ „ felspar, ii. 181.
„ „ fluor-spar in dykes, i. 14.
„ „ melaphyr, iii. 206.
„ „ silicates, i. 6.
„ „ sulphates in sea-water, i. 103.
Deltas, strata in, i. 137, iii. 20.
Deposition of inorganic substance in plants and minerals, ii. 373.
„ of mud, iii. 20.
„ „ influence of tides on, i. 138.
„ of carbonate of lime, i. 146, iii. 7, 117.
„ of limestone, iii. 34.
„ of carbonates of lime and magnesia from water, iii. 168.
Deposits, calcareous, i. 125, 146.
„ chemical, i. 140.
„ ferruginous, i. 148, 155.
„ fluviatile, i. 134.
„ marine, i. 138.
„ mechanical, i. 118.
„ from springs, i. 141.
„ under Amsterdam, iii. 39.
„ on thorn faggots, iii. 150.
Detritus transported by rivers, i. 63.
Diallage, ii. 331
Diopside, association with other minerals, ii. 306.
Diorite, iii. 274.
„ conversion of, into chlorite and talc-slate, iii. 312.
Dolerite, 233.
Dolomite, iii. 155.
„ conversion of limestone into, iii. 166.
„ in contact with dykes, iii. 179.
„ manganese ores in, iii. 194.
„ rocks associated with, iii. 199.
Dykes, basaltic, iii. 245.
„ clay-slate in, iii, 124.
„ dolomite in contact with, iii. 179.
„ fluor-spar in, i. 14.
„ phenomena presented by, iii. 73.

E.

Elæolite, alteration of, ii. 145.
Elevation by errupted masses, iii. 54.

Embolite, iii. 517.
Encrinites consisting of carbonate of lead, i. 44.
Epidote in melaphyr, iii. 229.
Erythrite, ii. 159.
Euphotide, felspar in, ii. 218, iii. 301.

F.

Felspar, ii. 158.
„ crystals with nuclei of kaolin, i. 38.
„ in cavities of grauwacke, ii. 164.
„ euphotide, ii. 217, iii. 301.
„ hornblende rock, iii. 274, 297.
„ sandstone, iii. 114.
„ syenite, iii. 282.
„ of the smelting furnace at Sangerhausen, ii. 164.
„ oxygen ratio of alumina and silica in different species of, iii. 268.
„ porphyry, iii. 419.
„ pseudomorphous, ii. 140, 147.
„ decomposition by carbonates of lime and iron, ii. 184.
„ „ salts of lime and magnesia, i. 12.
Felstone, pseudomorphous, ii. 186, iii. 431.
Fluocerite, iii. 517.
Fluorides, iii. 517.
Fluorine in apophyllite, ii. 155.
„ minerals, ii. 10, iii. 546.
„ sea water, i. 108.
„ not detected in augitic rocks, ii. 5.
Fluor-spar, displacement by chlorite, ii. 408.
„ formation of, ii. 5.
„ in dykes, i. 14.
„ occurrence of, ii. 5.
„ pseudomorphs after, i. 14.
„ removal from lodes, i. 35, 51.
„ in lodes, i. 441, iii. 546.
Formulæ, chemical, i. 48.
Fossil remains, alteration of, iii. 25.
„ „ in felspar-porphyry, ii. 163.
„ „ granular limestone, iii. 143.
„ „ zinc-blende in, i. 43.
Fusibility, influence of pressure on, i. 32.

G.

Gabbro, ii.
Gahnite, iii. 449.
Galena, iii. 466.
„ in fossil remains, i. 43.
Ganges, material carried into the sea by, i. 121.
Garnet, ii. 283.
„ no evidence of its igneous origin, ii. 287.
„ associated with chlorite, ii. 407.
„ erratic blocks containing, ii. 287.
„ from mica slate, iii. 348.
German Ocean, water of, i. 99.
Gigantolite, analysis of, ii. 352.
Glaciers and avalanches, i. 65.
„ water from, i. 119.
Glacier-streams, iii. 27.
Glassy felspar, ii. 187.
„ in lava, ii. 199.
Gmelenite, ii. 152.
Gneiss at Hekelfjord, ii. 341.
„ in connection with limestone, iii. 430.
„ conversion of diorite into, iii. 315.
Gold, iii. 534.
Grammatite, ii. 340.
Granite, iii. 409.
„ rarely effervesces with acids, i. 10.
„ origin of, iii. 47.
„ contact with clay slate, iii. 52.
Granulite, iii. 426.
Grauwacke, iii. 130.
Greenstone, iii. 298.
„ associated with augitic porphyry, iii. 209.
„ „ „ clay-slate, iii. 316.
„ „ „ limestone, iii. 309, 333.
Gypsum, deposition of, i. 112, 154.
„ conversion into carbonate of lime, i. 25.

H.

Harmotome calcareous, ii. 153.
Hausmannite, iii. 528.
Hematite red, conversion of limestone into, iii. 338.
Heulandite, alteration of, ii. 150.
Hornblende, ii. 339.
„ minerals associated with, ii. 340.
„ in melaphyr, iii. 223.
„ formation of, ii. 342.
„ aluminous, ii. 345.
„ without alumina, ii. 343.
„ alteration of ii. 346.
„ decomposition of, ii. 352.
„ pseudomorphous, ii. 315.
„ porphyry, iii. 287.
„ rocks, iii. 264.
„ „ alteration of, iii. 303.
„ „ bitumen in, iii. 314.

Horneblend rocks, conversion of gneiss into, iii. 315.
„ „ minerals associated with, iii. 304.
„ „ prehnite in, iii. 299.
„ „ quartzose, iii. 291.
Horneblend-slate, iii. 289.
„ „ origin of, iii. 316.

I.

Iberite, ii. 215.
Indianite, ii, 215.
Infusoria in bog-iron ore, i. 169.
„ mud, i. 134.
Insolubility merely relative, i. 29.
Iodine in sea-water, i. 108.
Iron, iii. 538.
„ carbonate of, iii. 493.
„ „ reaction with soluble sulphides, i. 15.
„ „ action of sulphuretted hydrogen upon, i. 25.
„ „ reaction with phosphate of lime, i. 13.
„ „ in sedimentary deposit, iii. 176.
„ magnetic oxide of, in augitic rocks, iii. 217.
„ ochre, i. 217.
„ oxides of, iii. 521.
„ „ action of sulphuretted hydrogen upon, i. 25.
„ „ reduction by organic substance, i. 168, iii. 1.
„ persilicate, ii. 129, iii. 442.
„ „ deoxidation by organic substance, i. 124, iii. 4, 67.
„ „ in water, i. 4.
„ phosphates of, iii. 512.
„ protosilicate of, ii. 129, iii. 442.
„ „ decomposition by carbonic acid, i. 3.
„ silicates of, ii. 129, iii. 441.
„ sulphate of, iii. 514.
„ „ reaction with bicarbonate of lime, i. 12.
„ sulphide of, deposits of, i. 162.
Iron-pyrites, iii. 452.
„ „ artificial production of, i. 25.
„ „ magnetic, iii. 455.
„ „ in organic remains, i. 42.
„ „ oxidation of, iii. 453.
Iron-spar, iii. 493.
„ „ manganese in, iii. 503.
„ „ peroxidation of, iii. 495.

J.

Jade, ii. 217.
Jasper in augitic rocks, iii. 208.

K.

Kaolin, analyses of, ii. 277.
„ mistaken for steatite, ii. 186.
„ in felspar crystals, i. 38.
„ conversion of albite into, iii. 195.

L.

Labradorite, ii. 206.
„ water in, iii. 225.
Lakes, i. 86.
Landslips, i. 64.
Laumontite, alteration of, ii. 147.
Lava, action on imbedded fragments of rocks, iii. 68.
„ crystallization of minerals in, iii. 50.
„ horneblende in, ii. 342.
„ production of trachytic rocks from, iii. 408.
„ protrusion in fissures, iii. 241.
„ similarity of old and recent, ii. 93.
„ trachytic, iii. 379.
„ leucitic, iii. 364.
Lead, iii. 538.
„ carbonate of, iii. 511.
„ chloride of, iii. 516.
„ oxide of, iii. 538.
„ phosphate, iii. 513.
„ silicate, iii. 447.
„ sulphate, iii. 515.
„ sulphide of, iii. 466.
Leadhillite, iii. 515.
Leonhardite, alteration of, ii. 150.
Lepolite, ii. 215.
Leptinite, iii. 412, 426.
Lettsomite, iii. 515.
Leucite, ii. 218.
„ analyses of, iii. 364.
Libethenite, iii. 513.
Lime, carbonate of,
„ displacement by prehnite, ii. 151.
„ „ in river-water, i. 80.
„ „ in schalstone, iii. 335.
„ „ in sea-water, i. 109.
„ „ removed by water, i. 70, iii. 199.
„ „ solubility of, i. 58.
„ „ solution and deposition of, iii. 192.
„ phosphate of,
„ „ reaction with alkaline carbonates and silicates, i. 13.

Lime, phosphate of, reaction with sulphates of iron and copper, i. 14.
" " " " fluoride of sodium, i. 14.
" silicate,
" " reaction with alkaline carbonates i. 8.
" " " " bicarbonate of iron, i. 13.
" " " " " of magnesia, i. 2.
" " " " fluoride of sodium, i. 14.
" " decomposition of, iii. 336.
" " in water, i. 5.
" sulphate of,
" " in river-water, i. 81.
" " reaction with alkaline silicates, i. 11.
" " " " chloride of barium, i. 17.
Limestone, iii. 116, 140.
" action of water on, i. 70, iii. 191.
" alteration of, iii. 188.
" associated with greenstone, iii. 309, 332.
" " " slate rocks, iii. 324.
" caves in, iii. 190.
" connection with red hematite, iii. 337.
" " " gneiss, iii. 430.
" conversion into dolomite, iii. 166.
" deposition of, iii. 34.
" granular, iii. 140.
" origin of minerals in, iii. 545.
" sedimentary, iii. 116.
" silicification of, iii. 432.
" silurian, iii. 121.
" transition, analyses of, iii. 337.
Linarite, iii. 515.
Linseite, ii. 215.
Lodes, iii. 433.
" classification of, iii, 438.
" clay-slate in, iii. 124.
" fluor-spar in, iii. 546.
" junction and intersection of, iii. 550.
" relation to rocks they traverse iii. 548.
" removal of calc-spar and fluor-spar from, i. 35, 51.
" sequence of minerals in, iii. 436.
" structure of, iii. 539.
" sublimation in, i. 34.
Loess, i. 127.
Lough Neagh, water of, i. 94.

M.

Magnesia, carbonate of, solubility of, i. 58.
" " river-water, i. 80.
" " deposits from water, iii. 177.
" " marly strata, iii. 181.
" hydrate of, reaction with bicarbonate of lime, i. 12.
" in sea-water, i. 109.
" silicate of, ii.
" " in water, i. 5.
" " reaction with fluoride of sodium, i. 14.
" " action of carbonic acid upon, i. 2.
" sulphate of,
" " reaction with alkaline silicates, i. 11,
" " " " chloride of barium, i. 17.
" " in Black Sea, water, i. 88.
" " river-water, i. 82.
" " rock-salt, i. 112.
" substitution for lime, i. 13.
Malachite, iii. 509.
Malacolite, minerals associated with, 306.
Manganese, carbonate of, iii. 506.
" in iron-spar, iii. 503.
" ores,
" in dolomite, iii. 187, 194.
" origin of, iii. 531.
" oxides of, iii. 522.
" " deposits of, i. 160.
" phosphate of, iii. 512.
" silicates, ii. 133, iii. 442.
" sulphide of, iii. 456.
Manganite, iii. 522.
Marl, analyses of, i. 127.
Meal-zeolite, ii. 147.
Mediterranean Sea, water of, i. 105.
Melaphyr, iii. 204.
" contact of rocks with, iii. 80.
" hornblende in, iii. 223.
" metals in, iii. 448.
" water in, iii. 226.
Mercury, iii. 537.
" sulphide of, iii. 469.
Mesolite, ii. 151.
Mesotype, composition of, ii. 151.
Metals, in sea-water, i. 109.
" disseminated through rocks, iii. 435, 448.
" native, iii. 534.
" in the water of springs, iii. 539.
Metamorphism, at St. Gothard, ii. 171.
" of clay-slate, iii. 327.
Mica, ii. 366.
" association with other minerals, ii. 350, 373.

Mica, composition of, ii. 368.
„ conversion of felspar into, ii. 172.
„ influence of heat on, ii. 374.
„ in Rhenish deposits, i. 126.
„ in sandstone, iii. 112.
„ occurrence and formation of, ii. 371.
„ relation to corderite, i. 84.
Mica-slate, iii. 341.
„ relation to clay-slate, iii. 346.
Minerals, abstraction, addition, and exchange of constituents, i. 21.
„ action of carbonated water on, i. 58.
„ alteration of, i. 1, 18, ii. 58, 103.
„ „ commencing at the centre, i. 38.
„ „ its gradual progress, i. 39, 46.
„ amorphous, alteration of, i. 50.
„ associated with horneblende rocks, iii. 304.
„ best mode of representing composition of, i. 49.
„ deposition of, analogous to that of inorganic substance in plants, ii. 373.
„ effervescence along capillary interstices of, i. 39.
„ essential and accessory constituents, i. 47.
„ importance of minute portions of substances in, i. 46.
„ in crystalline rocks, iii. 44.
„ in lava, iii. 50.
„ in lodes, iii. 433.
„ „ local incrustation of, i. 35.
„ normal condition of, i. 45.
„ paragenetic relations of, iii. 437.
„ petrifying, i. 42.
„ pseudomorphous, i. 18.
„ „ solubility of, i. 39.
„ separation of water from, i. 38.
„ solubility of, i. 59.
Mispickel, iii. 474.
Mississippi, suspended substance in, i. 121.
Molybdates, iii. 487.
Molybdenum, oxide of, iii. 520.
„ sulphide of, iii. 470.
Mud, infusoria in, i. 134, iii. 109.
„ deposition of, influence of tides and wind on the, i. 138.
„ from bottom of ocean, iii. 109.

N.

Natrolite, pseudomorphous, ii. 144, 146.
„ in basaltic amygdaloid, iii. 261.
Nepheline, in augitic rocks, iii. 216.
Nepheline, in rocks, iii. 259.
„ rock, analysis of, iii. 260.
Nickel, carbonate, iii. 511.
„ sulphate of, iii. 515.
„ sulphide of, iii. 469.
Nile mud, analyses of, i. 133.
Nussierite, iii. 514.

O.

Obsidian, iii. 385, 397.
Ocean, carbonate of magnesia in, iii. 178.
„ suspended substance in.
„ „ „ deposition of, i. 138.
Ochre, silica in, i. 4.
Oligoclase, ii. 195.
„ in augitic rocks, iii. 215.
Olivine, ii. 356.
„ rocks in which it occurs, ii. 356.
Onyx, artificial colouring of, ii. 414.
Ores, production of, iii. 552, 548.
Organic remains in rocks, i. 40.
„ „ associated with silver and sulphide of copper, i. 44.
„ „ influence in the production of sulphides, iii. 554.
„ substance, in river-water, i. 83.
Orthoclose, ii. 158.
„ conversion into albite, ii. 168.
„ connection with laumontite, i. 148.
Oxides, metallic, iii. 517.
„ „ silicates of, iii. 441.
Oxygen in sea-water, i. 113.
Oxygen quotients of aluminous augite, ii. 314.

P.

Palagonite, solution by water, i. 31.
Palladium, iii. 535.
Pearlstone, iii, 393.
Perthite, ii. 159.
Petrifactions, production of, i. 40.
Phonolite, iii. 353.
Phosphates, i. 23.
Phosphochalcite, iii. 513.
Phosphoric acid in sea-water, i. 108.
Pitchstone, iii. 393.
Platinum, iii. 535.
Porphyry augitic, iii. 204.
„ trachytic, iii. 383.
„ felspathic, iii. 419.
Potash, silicate of, ii. 115.
„ „ action of carbonic acid upon, i. 2
„ „ reaction with bicarbonate of lime, 12.

2 0 2

Potash, silicate of, reaction with chloride of sodium, i. 32.
" substitution for lime, i. 5.
Prehnite pseudomorphous, ii. 142, 146, 147, 150, 152.
" in hornblende rocks, ii. 292.
Protogyne, iii. 422.
Pseudomorphism, i. 23.
Pseudomorphous albite, ii. 174.
Pseudomorphs, i. 14.
" after calc-spar, iii. 174.
" classification of, i. 14.
" generally porous, i. 30.
" geological importance of, i. 49.
" most frequent where water circulates most copiously, i. 45.
" not of igneous origin, i. 32.
Psilomelan, iii. 524.
Pumice stone, iii. 397.
Puzzolano, iii. 405.
Pyrites, copper, iii. 457.
" production from grey copper ore, iii. 460.
" iron, iii. 452.
Pyrolusite, iii. 529.
Pyromorphite, iii. 512.

Q.

Quartz, ii. 454.
" dykes in serpentine, ii. 428.
" in deposits from the Rhine, i. 126.
" in lodes, iii. 543.
" production of ii. 469.
" pseudomorphous, ii. 150, 479.
" and sulphides in lodes, iii. 545.
" crystallization of, ii. 97.
" associated with tourmaline, ii. 255.
" " bitter-spar, iii. 162.
" crystals in lava, iii. 50.
" in melaphyr, iii. 227.
" in sandstone, iii. 93.

R.

Red porphyry of Ilmenau, ii. 184.
Red zeolite, ii. 147.
Rhine, suspended substance of the, i. 123.
Ripidolite, ii. 407.
Rivers, i. 75.
" connection with lakes, i. 87.
" deposits from, iii. 31.
" transport of detritus by, i. 68, iii. 33.
Rock-water, i. [illegible].
" constituents of, i. [illegible].
" carbonates in, i. [illegible], [illegible].
" chlorides in, i. [illegible].
Rocks, augitic, iii. [illegible].
" action of carbonic water on, i. [illegible].
" " alkalies on, iii. [illegible].
" analyses of, iii. [illegible].
" basaltic, iii. [illegible].
" calcareous, solution of, i. [illegible].
" carbonates in, i. [illegible].
" classification of, iii. [illegible].
" columnar structure of, iii. [illegible].
" constituents of, relative to substances in water, i. [illegible].
" containing augite, iii. [illegible].
" crystalline, iii. [illegible].
" general characters, iii. [illegible].
" granitic, iii. [illegible].
" hornblendic, iii. 364.
" influence of heat on, iii. [illegible].
" leucitic, iii. 353.
" metals disseminated through, iii. 434.
" metamorphic, iii. 65.
" nepheline in, iii. 258.
" phonolitic, iii. 353.
" relation to granite, iii. 428.
" sedimentary, iii. 18.
" trachytic, iii. 369.
" trapp, composition of, iii. 258.
Rosite, ii. 215.
Rutile, iii. 519.
Ryakolite, ii. 191.

S.

Sandstone, iii. 93.
Sanidine, ii. 187.
" analyses of ii. 187, 188.
" formation of, ii. 189.
Saussurite, ii. 217.
" relation between it and anorthite, ii. 218.
Scapolite, ii. 215.
Schalstone, iii. 329.
" carbonate of lime in, iii. 335.
Sea-water, gases in, i. 112.
" substances in, i. 98.
" uniform composition of, i. 102.
Seleniides, iii. 476.
Sequence in the formation of minerals, ii. 412.
Shale, iii. 137.
Silica, decomposition of carbonates by, i. 6, ii. 181.
" in sea-water, i. 109.
" in mineral water, ii. 182.
Silicates, iii. 441.
" action of carbonic acid upon, i. 2.

Silicates, alkaline, decomposition by carbonate of lime, iii. 14.
„ „ reaction with calcareous and magnesian salts, i. 11.
„ in water, i. 11, 83.
„ decomposition of, i. 6.
„ metallic, iii. 441.
„ in dolomite and limestone, iii. 163.
Silver, iii. 535.
„ bromide, iii. 516.
„ carbonate of, iii. 512.
„ chloride, iii. 516.
„ iodide, iii. 517.
„ native, iii. 5.
„ silicate, iii. 447.
„ sulphide of, iii. 469.
Sinter, calcarcous, i. 150.
Skolezite, ii. 152.
Slate transition, iii. 136.
„ composition of, iii. 320.
„ rocks, iii.
„ „ granular limestone associated with, iii. 324.
Soda, silicate of, iii. 115.
„ „ action of carbonic acid upon, i. 2.
„ felspar, separation from potash-felspar, ii. 172.
„ lakes, i. 93.
„ mesotype, ii. 144.
„ spodumene, ii. 195.
Solubility of mineral substances proved by petrifactions, i. 30, 41, 59.
Sphœrosiderite, i. 157.
Spodumene, ii. 202.
Springs, i. 67.
„ deposits from, i. 141.
„ incrusting, i. 152.
„ ferruginous deposits, i. 148, 155.
Sprudelstone, analyses of, i. 149.
Steatite, conversion of felspar into, ii. 173.
Stilbite, ii. 150.
Sublimation, alteration effected by, i. 34.
Sulphates, alkaline, ii. 416.
„ decomposition by organic substance, i. 15.
„ earthy, ii. 418.
„ metallic, iii. 514.
Sulphides, iii. 450.
„ alkaline and earthy, ii. 327.
„ „ „ reaction with hydrated peroxide of iron, i. 15.
„ arsenical, iii. 474.
„ compound, iii. 470.
„ metallic, iii. 450.
„ in sea-water, i. 114.
„ production of, i. 17, 163, iii. 450, 553.
„ silver in, iii. 516.
Sulphuretted hydrogen in water, i. 15.
Syenite, iii. 279.
„ comparison with clay slate, iii. 326.
„ hydrated minerals in, iii. 266.

T.

Talc, pseudomorphous, ii. 143.
Talc-slate, iii. 352.
„ conversion of diorite into, iii. 313.
Tantalates, iii. 482.
Tellurides, iii. 479.
Tellurium, oxide of, iii. 520.
Tile-ore, iii. 532.
Tin, oxide of, iii. 517.
„ sulphide of, iii. 470.
Tin-ore, conversion of felspar into, ii. 176.
Titantes, iii. 480.
Titanic acid, iii. 519.
Trachyte, iii. 369.
Trachytic, conglomerate, ii. 189.
„ „ of sedimentary
„ origin, ii. 189.
Trap, iii. 405.
Triphane, ii. 202.
Triphylin, iii. 513.
Troostite, iii. 444.
Tuff, trachytic, iii. 404.
Tungstates, iii. 484.
Tungsten, oxide of, iii. 520.

U.

Uralite, analyses of, ii. 316.
Uranium, carbonate of, iii. 512.
„ oxide of, iii. 534.
„ phosphate of, iii. 514.
„ silicate of, iii. 443.
„ sulphate of, iii. 515.

V.

Vanadates, iii. 489.
Vanadium, iii. 520.
Veins, basaltic, iii. 245.
„ metalliferous, iii. 433.
Volger on the association of chlorite with other minerals, ii. 409.
„ on the formation of chlorite, ii. 415.

W.

Wad, iii. 530.
Water, alkaline carbonates in, i. 1.

Water, alkaline carbonates in, [illegible]
„ „ „ [illegible], i. [illegible]
„ „ silicates in, [illegible]
„ carbonate of ammonia in, [illegible]
„ carbonated, [illegible] of [illegible] by, [illegible]
„ „ action on [illegible], i. [illegible]
„ „ „ limestone, ii. [illegible]
„ carbonates in, ii. [illegible]
„ [illegible]
„ [illegible]
„ formation of, i. 82.
„ from [illegible], i. [illegible]
„ influence in the decomposition of rocks, ii. 182.
„ of mines, [illegible] of, i. 12[illegible]
„ meteoric, i. 82.
„ „ action upon rocks, i. 82.
„ mineral substances in, i. 30.
„ „ „ alteration effected by, i. 24.
„ „ „ relation to consistence of rocks, i. 1.
„ „ silica in, ii. 182.
„ organic substances in, i. 82.
„ permeation of rocks by, i. 58.
„ of rivers, i.
„ „ chlorides in, i. 82.
„ „ substances in, i. 84.
„ of the sea, i. 96.
„ „ „ fluorine in, i. 168.
„ „ „ decomposition of sulphates in, i. 163.
„ separation from minerals, i. 38.
„ silicates in, i. 4.
„ solution of apophyllite by, i. 31.
„ of springs, mineral substances in, i. 1, 74.
„ subterranean course of, i. 67.
„ sulphuretted hydrogen in, i. 15.
Water, [illegible] of [illegible] of [illegible], [illegible] ii. [illegible]
„ [illegible], ii. [illegible]
Water-[illegible], [illegible] of, iii. [illegible]
W[illegible], ii. [illegible]
„ „ [illegible] of, i. [illegible]
W[illegible], i. [illegible]
W[illegible], ii. [illegible]
W[illegible], [illegible] of, i. [illegible]

X.

X[illegible], ii.

Y.

Y[illegible], ii. [illegible]

Z.

Zeolites, ii. 136.
„ alteration of, ii. 1[illegible]
Zinc, carbonate of, iii. 5[illegible]
„ „ reaction with sulphate of potassium, i. 1[illegible]
„ „ „ silicate of soda, i. 12.
„ oxide of, iii. 5[illegible]
„ silicate, i. 66, iii. 44[illegible]
„ sulphate,
„ „ reaction with bicarbonate of lime, i. 12.
„ sulphide, iii. 456.
„ „ deposits of, i. 164.
Zoisite, iii.

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REPORT

OF

THE ELEVENTH ANNIVERSARY MEETING

OF THE

CAVENDISH SOCIETY.

THE Anniversary Meeting of the Cavendish Society for the year 1858, was held at the rooms of the Chemical Society, in Burlington House, on Monday, the 1st of March, at three o'clock in the afternoon.

The Chair was taken by THOMAS GRAHAM, ESQ., F.R.S., PRESIDENT, who called upon the Secretary to read

THE REPORT OF THE COUNCIL.

"Since the last Anniversary Meeting of the Cavendish Society, the Council have been enabled to supply to the Members only one book,—the eleventh volume of GMELIN'S 'Hand-book of Chemistry.' They regret that the second book for 1856 is still in arrear, and that there is a similar arrear for 1857. The concluding volume of BISCHOF'S 'Elements of Chemical and Physical Geology' was the work with which the Council had intended to supply the deficiency for the former of these years. The delay in finishing this work was adverted to in the Report at the last annual meeting, since which time but little progress has been made with it, although the prospect of its speedy completion has, until recently, been held out by the author. As the illness which has caused this delay still continues, the Council have decided to issue the twelfth volume of GMELIN'S 'Hand-book of Chemistry,' now in the press, as the second book for 1856. With reference to the second book for 1857, some time was occupied in making the preliminary arrangements. After much consideration, and a careful investigation of the merits of several works which had been suggested, it was concluded to bring out a new edition of ROSE'S 'Analytical Chemistry,' which will be translated and edited by Mr. T. H. Henry, and will have much new matter added to it by Professor Rose himself. The Council think this arrangement will ensure the production of a work on Analytical Chemistry worthy of association with the works already issued by the Society on other branches of Chemical [illegible] Mr. [illegible] has made some progress with the tran [illegible] which will be supplied to members as the [illegible] The entire work will occupy four volumes. [illegible] with a volume of GMELIN's 'Chemistry [illegible] arrangement made by the Council, be pr [illegible] year until the completion of one or both of these work [illegible] the delay referred to in completing the [illegible] that the diminution in the subscri [illegible] is chiefly to be ascribed. The C [illegible] the Members of the Society will give them cre [illegible] their best endeavours to avoid any unnecessary [illegible] withhold their support or defer the pa [illegible] subscriptions while the important works, [illegible] the Council have committed themselv [illegible] referred to, however, [illegible] a falling off in the number of subscribers [illegible] circumstance, that those who are desirous of j [illegible] difficulty in doing so, without [illegible] from the beginning, or having imp [illegible] progress of publication. Thus, while m [illegible] have been removed by death and [illegible] has been presented to the accession of an [illegible] members, and this difficulty has become g [illegible] the Society have increased.

[illegible] have endeavoured to meet this difficulty by a [illegible] have left on hand in set [illegible] any of these, and thus to [illegible] course of publication, wi [illegible] works concurrently issued. [illegible] this Report for circu [illegible] the Council beg to suggest that an [illegible] present time to increase the numb [illegible] Society. By this doing they will enab [illegible] greater amount of matter in return fo [illegible] more rapidly with its pre [illegible] successful in getting the vo [illegible] reason to anticipate f [illegible] confidence in the punctuality o [illegible] and Rose's 'Analytical [illegible] in course of publication."

STATEMENT of the RECEIPTS and EXPENDITURE of the CAVENDISH SOCIETY, from the 1st of March, 1857, to the 26th of February, 1858.

RECEIPTS.	£	s.	d.	EXPENDITURE.	£	s.	d.
Balance from previous year	194	2	9	Stationery, Postage, Advertisements, &c.	17	19	6
3 Subscriptions for 1848	1	11	6	Insurance..	2	4	0
1 Ditto 1852	1	1	0	Collector's Commission	9	13	6
5 Ditto 1853	5	5	0	Secretary, to 1st March, 1857	100	0	0
5 Ditto 1854	5	5	0	Editorial expenses	155	5	0
17 Ditto 1855	17	17	0	Paper	95	14	9
37 Ditto 1856	38	17	0	Printing	145	7	0
225 Ditto 1857	236	5	0	Binding and wrapping	115	1	8
127 Ditto 1858	133	7	0				
Subscriptions from America	139	4	6		641	5	5
33 Sets of GMELIN'S 'Inorganic Chemistry'	69	6	0	Balance in hand	200	16	4
	£842	1	9		£842	1	9

We have examined the above statement, and find it correct.

ANDREW C. RAMSAY.
HENRY POLLOCK.

March, 1858.

It was resolved—

"That the Report just read be received, approved, and adopted."

The Meeting then proceeded to the election of Officers for the ensuing year, and the following Gentlemen were declared to have been duly elected:—

President.

Thomas Graham, F.R.S.

Vice-Presidents.

Professor Brande, F.R.S.
Duke of Devonshire, F.R.S.
Walter Crum, F.R.S.
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George Dixon Longstaff, M.D., 9, Upper Thames Street.

Secretary.

Theophilus Redwood, Ph. D., 19, Montague Street, Russell Square, and 17, Bloomsbury Square.

Collector.

Mr. Thomas West, Burlington House, Piccadilly.

Agent for the Distribution of Books, &c.

Mr. Harrison, 59, Pall Mall.

It was resolved—

> "That Mr. Charles Heisch, Dr. Marcet, and Mr. N. S. Maskelyne, be appointed Auditors for the ensuing year."

The following Resolutions were unanimously adopted:—

> "That the thanks of the Meeting be given to the President, Treasurer, and Council, for their services to the Society."
>
> "That the thanks of the Meeting be given to the Honorary Local Secretaries for their services to the Society."
>
> "That the thanks of the Meeting be given to the Chemical Society for the use of their rooms on the present occasion."

The Meeting was then adjourned.

THEOPHILUS REDWOOD, Secretary,
19, Montague Street, Russell Square,
and 17, Bloomsbury Square.

March, 1858.

Honorary Local Secretaries.

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